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REPORT

OF

GENERAL HERMAN HAUPT, C. E.,

ON

THE HOLLY DISTRICT SYSTEM

OF

STEAM HEATING

FOR

CITIES AND VILLAGES.

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REPORT

UPON THE SYSTEM OF THE

HOLLY STEAM COMBINATION COMPANY LIMITED,

OF LOCKPORT, N. Y.,

FOR THE INTRODUCTION OF THE

District System of Steam Heating

FOR

CITIES AND VILLAGES.

BY

GENERAL HERMAN HAUPT,

GRADUATE OF WEST POINT, CLASS OF 1835, AT AGE OF 18; ENTERED SERVICE OF PENN'A AS ENGINEER STATE WORKS, 1838; PROFESSOR CIVIL ENGINEERING AND MATHEMATICS IN PENN'A COLLEGE, 1840–1847; SUCCESSIVELY GENERAL SUP'T, CHIEF ENGINEER, AND DIRECTOR OF PENN'A R R. UNTIL 1856; AUTHOR OF GENERAL THEORY OF BRIDGES, 1852; THE FIRST ONE PUBLISHED GIVING RULES AND FORMULA FOR CALCULATING THE STRENGTH OF BRIDGES; CHIEF ENGINEER AND CONTRACTOR FOR HOOSAC TUNNEL, 1856–1862; CHIEF OF CONSTRUCTION AND OPERATION OF THE MILITARY RAILROADS OF THE U. S.; AUTHOR OF WORK ON MILITARY BRIDGES, 1863; GENERAL MANAGER OF THE LINE OF RAILROADS KNOWN AS THE PIEDMONT LINE, FROM RICHMOND, VA., TO ATLANTA, GA., 1872 TO 1876; CHIEF ENGINEER OF SEABOARD PIPE LINE, 1876 TO 1879.

OFFICERS.

D. F. BISHOP, M. D., *President.* B. D. HALL, *Secretary.*
SAMUEL ROGERS, *Vice President.* I. H. BABCOCK, *Treasurer.*
BIRDSILL HOLLY, *Superintending Engineer.*

LOCKPORT, N. Y.:
UNION PRINTING AND PUBLISHING COMPANY, JOHN HODGE, PRESIDENT.

1879.

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INTRODUCTION.

In submitting to our present and prospective patrons, and to the public generally, the report of General Haupt, The Holly Steam Combination Company Limited desire to state that this very thorough examination of the Holly System was made by General Haupt, not in the interest or by request of this Company, but for other parties, in no manner connected therewith, who required the professional indorsement of this gentleman, before committing themselves to the responsibilities of an organization for the introduction of the System in the city of New York.

The report was so exhaustive, and supplied so fully the information and the data required by all companies who propose to introduce the Holly System, that it has been extended, and valuable tables added by the author, and is now published by this Company for the benefit of its patrons.

Applications for the right to use the Holly System are multiplying so rapidly, that it has already become embarrassing for this company to undertake to furnish engineering services in preparing plans and estimates, or skilled foremen to superintend the construction of works. To meet these wants, General Haupt proposes to organize a corps of assistants, consisting chiefly of graduates of the first engineering schools, and with their aid make surveys, prepare plans and estimates, and when desired, superintend the construction of works. Also to organize

a construction company, prepared to make contracts for doing the work, when parties prefer such an arrangement.

It will, of course be optional with local organizations to adopt any plan for constructing their works that may seem to them to be most to their interest; they can either employ a superintendent and hire hands, or let out the work by contract; but in all cases this company must protect itself against the injury that would result from defective construction by insisting on the right of supervision, with proper stipulations, in any contract that may be hereafter made, for its enforcement.

The Company also reserve the right in all their contracts to supply the expansion service boxes, regulators, metres, and traps, which are secured to them under the Holly patents, so as to insure proper mechanical excellence in construction These articles are furnished at list prices, which average a very small margin on cost of manufacture.

LOCKPORT. N. Y., March 28, 1879.

REPORT OF HERMAN HAUPT, C. E.

To the President and Directors of the Holly Steam Combination Company Limited:

GENTLEMEN:—I herewith submit my report containing the results of investigations as to the practicability, utility, economy and advantages of the Holly System for furnishing heat and power.

The subject was, with possibly a single exception, the most difficult that I ever undertook to investigate, from the fact that the few who have written on the transmission of elastic fluids through pipes have given rules and formula which were found to be in their results inconsistent with each other and with facts proved by direct experiment, and some of the experiments as reported have given results incompatible with each other.

To reconcile these inconsistencies and develop a theory that would conform to known and established principles of pneumatics, and, at the same time, be consistent with the facts elicited from direct experiment, proved to be a most difficult task, and yet a satisfactory solution was indispensable, as on it must necessarily be based the solution of all questions as to the capacity of mains, the losses by radiation and friction, the sizes and locations of boilers, and all other fundamental considerations affecting the determination of plans of operations, capital, operating expenses, profits and dividends.

It might have been supposed that a report less voluminous and in detail would have been preferable, as the general reader cares but little except for results, and is not disposed to follow the processes of reasoning or of calculation by which the results are reached; but the fact that rules, formulas and conclusions in this report are different from, and in some particulars at variance with the rules and formulas of the books, renders it necessary that the discussion of the subject treated upon should be as complete and demonstrative as possible.

The practical tables which accompany the report have involved much labor, and should be of value in dispensing with intricate calculations, and in reaching results by simple inspection.

A brief abstract of the report and the conclusions arrived at will be given:

1. The report commences with a description of the Holly System, and of the apparatus in detail, as also the manner of protecting the mains with coatings of non-conducting material.

2. Table of the relative conducting power of different materials with suggestions of improvements.

3. Explanation of facts observed in connection with junction boxes.

4. Suggestion of a governor for maintaining, at all hours of the day or night, a temperature almost perfectly uniform.

5. The discharge of fluids through pipes considered in connection with the discoveries by Napier of apparent exceptions to the general law.

6. Resistance of long pipes to the flow of elastic fluids, and laws which govern it. Experiments in friction of pipes with air at the Mt. Cenis Tunnel.

7. New law enunciated for the discharge of elastic fluids which is, that the discharge of elastic fluids through long pipes is equal to the corresponding water discharge under like conditions, multiplied by the square root of the number which expresses the relative density, as compared with water, and the product multiplied again by the square root of the initial density in atmospheres. The result will give the volume of discharge under atmospheric pressure.

8. Table of initial pressures in atmospheres, initial densities as compared with water, and volume of discharge of steam, the water discharge being unity.

9. Demonstration of the law of discharge of elastic fluids through long pipes.

10. Reduction of terminal pressure at the end of a long pipe in consequence of drawing off at intermediate points, the laws which govern it, and rules for its determination.

11. Discussion of important experiment at Lockport, using the cylinder of a large engine as a meter to measure the steam discharged in a given time, which confirms the law of discharge previously stated.

12. Additional confirmation of this law from the Mt. Cenis experiments, which give the exact loss by friction deduced from theory.

13. Table giving the lengths of pipes of different diameters equivalent in frictional resistance to one mile of one inch pipe, for the purpose of equalizing resistances in calculations when pipes of different diameters are connected.

14. Consideration of formula for determining loss of head by friction.

15. Table of loss of head by friction for initial velocities of 5 to 400 feet, and diameters of pipe of from 1 to 12 inches.

16. Consideration of the capacity of mains and the velocity of steam.

17. Table of the discharges of steam at atmospheric density under pressures of from 5 to 60 pounds and diameters of from 1 to 12 inches; a table which has required much labor in calculation, but which will save much labor hereafter in computation.

18. A record of experiments, facts and observations, communicated by Mr. Holly, is given, numbered from 1 to 11; and these are fully discussed, and important practical conclusions deduced therefrom, chiefly in regard to losses by condensation and radiation, and affording data for estimates of cost and saving by the Holly System.

19. A table is given of the relative losses by condensation in one mile of pipes of different diameters, which shows the loss to be 1.9 per cent. in a mile of 12 inch pipe.

20. The subject of the transmission of heat by a circulating pipe of water, is discussed in detail, and the conclusions are as follows, viz:

The water that can circulate in 2 miles of 6 inch pipe under 350 pounds pressure, will be only 1.85 cubic feet per second. Steam will move with 285 times greater velocity, and discharge a corresponding increase in quantity.

It is only the units of heat capable of being utilized that can be considered of value, those which are circulated and returned to the boiler produce no useful result.

The proportion of *available* units transported in a given time is more than 2 to 1 in favor of steam. It costs precisely as much to generate heat units in water as in steam, both being proportionate to fuel consumed.

Two pipes are required for hot water, and only one for steam, and the cost of the water pipes is fully as much as for steam pipes.

The radiating surface and the loss by cooling are much greater in water than in steam pipes, in consequence of the double pipe for return and high temperature employed.

On the basis of equal expenditure for mains, the steam pipe, in proportion to available units transported, would have an advantage of 12 to 1 over the hot-water pipe.

The condensed steam from hot water cannot be returned to the mains without pumps, as the pressure would be from 1 to 150 pounds.

It will require more than the whole engine power of the boiler to pump the water back after it has made its circuit.

The hot-water system cannot be utilized in any manner without the expansion joints and service boxes covered by the Holly patents.

The hot water cannot be used as a fuel to generate steam.

To use it as steam under reduced pressure is not as economical as to use steam direct.

The hot-water scheme is utterly impracticable, and the liability to explosion in consequence of the high temperature proposed to be used would be much greater than with steam. The only way to utilize the hot-water pipe would be to dispense with the return main and pump, and use it for heating in indirect coils, but in this form it is part of the Holly System, and covered by the Holly patents.

21. The next subject discussed is the cost of warming an average building of 12,000 cubic feet as compared with the old system, showing actual cost of fuel about 30 per cent., or a saving 70 per cent.

22. Estimate of plant and capacity of a 6-inch main to supply consumers at an average distance of one mile.

23. Estimate of capacity of boilers and mains for warming one square mile in a large city.

24. Table of number of consumers which pipes of different diameters can supply at one mile of distance.

25. Table of quantity of water evaporated per pound of coal under different pressures.

26. Estimate of cost of plant, operating expenses and profits in supplying an area of one mile square in a populous city.

27. Considerations affecting the location of the boiler stations, and relative cost of carrying steam or of carting coal.

28. Power furnished from street mains.
29. Suggestions as to plans of operations.
30. Report on the Ashcroft steam stove.

These subjects are fully discussed in the detailed report, and the process of reasoning by which the conclusions are reached can be readily followed. Independently of the great benefits conferred upon the public, few investments at the present day offer so large a return upon capital, with so little risk. The present investigation seems to have removed the only element of uncertainty, which was the required capacity of mains for a given consumption, and calculations can now be made with as much certainty as in estimating upon gas or water works.

An estimate is submitted of the cost of plant, expenses of operation and profits on one mile of 6-inch pipe, giving capital invested, $32,600; operating expenses, $14,900; income, $23,400; surplus, 73 per cent., applicable to extensions or dividends, and this estimate is based on a consumption 30 per cent. less than the full capacity of the pipe, if consumers were uniformly distributed along its entire length, which would be 536 consumers.

A six-inch pipe, however, would supply only a small village containing a population of say 2,000 inhabitants. A twelve-inch main (if consumers were uniformly distributed along its route for one mile) would supply about 3,000 consumers, and the margin of profit with a consumption equal to its capacity, would be largely increased; for, as the ratio of consumption increases the proportion of general expenses and the cost of plant diminishes.

An estimate is submitted of the cost of supplying one square mile in a populous city, such as New York, from which it appears that nearly 10,000 horse-power of boilers will be required, 116,000 feet of 12-inch mains, 27,500 feet of $3\frac{1}{2}$-inch pipes, 50,000 feet of $2\frac{1}{2}$-inch pipes, 100,000 tons of coal annually, and 150 firemen and laborers. The capital invested will be slightly in excess of a million of dollars; the expenses $526,000. The income on a basis of $100 to each consumer of 12,000 cubic feet, on the basis of the Lockport estimates, and full capacity of mains utilized will be $2,000,000 and profits 140 per cent.; but at half-rates of charges and full consumption the profits will still be 66 per cent.

The question is also considered as to the expediency of locating the

boiler station near a convenient source of coal supply and extending mains to a greater distance, and the conclusion reached is, that it is much cheaper to cart coal than to carry steam, and that the station or stations should be located as near as possible to the consumption.

The report on the steam stove exhibits remarkable results. There are few kinds of cooking that cannot be done satisfactorily, and at the temperature due to 40 pounds pressure. Baking, broiling and frying can be done with great expedition. Nothing can be scorched, and the flavor of all meats, vegetables, fish, etc., is very superior to that of dishes prepared in the ordinary way.

The cost of fuel measured by steam consumed is almost incredibly small; and for the poorer classes, occupying tenement houses, the stove could serve as a radiator and furnish all the heat necessary, as well as cook the food, at a cost of a very few cents daily.

The combination of the steam stove with the Holly System would be a great boon to all classes, but to the poor especially. The security against fires should be largely increased and the insurance rates diminished.

Respectfully submitted,

H. HAUPT,

Consulting Eng'r, 328 Walnut street, Phila.

DETAILED SCIENTIFIC REPORT OF H. HAUPT ON THE HOLLY STEAM COMBINATION SYSTEM.

To the President and Directors of the Holly Steam Combination Company Limited:

GENTLEMEN:—In compliance with your request, I visited Lockport to examine into the practical working of your system for supplying heat and power to cities and other populous localities, and to satisfy myself and others who desired my opinion as to the reliability of the tests and experiments made by your engineer, Mr. Birdsill Holly.

After a sojourn of eight days at Lockport, during which every facility for examination was afforded and some of the more important experiments repeated, I am able to report that I am more than satisfied. My friends charge me with being an enthusiast; with having steam on the brain; but if I have caught the infection, it is at least some consolation to know that it is becoming epidemic, and that the marked success which has attended the introduction of the system in Lockport has resulted in so many inquiries and applications from other localities that an expanded organization is already required to attend to them. To dispense with coal-bins, dust, dirt and attendance; to avoid the alternations of summer heat and winter cold at short intervals; to remove the embellishment of ash-barrels on the curb-stone, and secure a constant, uniform temperature at all times, at less than the former cost of fuel, are luxuries which once enjoyed will never again be willingly dispensed with.

But the capabilities of the system do not end here. The uses for small powers for manufacturing and other purposes would be greatly extended if such powers could be supplied without boilers, skilled at-

tendance or possibility of explosion, and with no expense except when in actual use.

It is, perhaps, not unreasonable to predict that the introduction of this system will extend the uses and the applications of the electric light, one of the principal objections to which is the power required to rotate the magnets; but this power, after the introduction of steam mains, can be furnished like gas, simply by turning a cock, and at *no cost whatever;* for the steam, when it has done its work, can escape into the radiator, and pay for itself in warming the apartment, so that a wide door is thus opened for the use of the electric light for domestic purposes.

In confidently endorsing the Holly System, it is necessary to explain the grounds of this confidence, and I propose to explain the System and its operation, determine the losses from friction and condensation, ascertain the distance to which steam can be economically transmitted, the velocities of transmission, the capacities absolute and relative of mains, the quantity required to be furnished in a given locality, and such other details as may present themselves in the discussion of the questions submitted, and which may appear to be necessary for their satisfactory solution.

DESCRIPTION OF THE HOLLY SYSTEM.

The Holly System consists in the generation of steam at a central point, its transmission by well-protected mains to localities more or less remote, and its utilization by means of various ingenious and practical mechanical devices.

It is supplied to the consumer in the same manner as gas, and is paid for in proportion to the amount used, as indicated by a meter.

It dispenses with fires and their attendant annoyances and discomforts, resulting from carelessness of servants, dust drawn through the registers where furnaces are used, the trouble of preparing kindlings and lighting fires that have become extinguished, of removing ashes, and especially of the liability to colds and inflammatory diseases from the sudden and great changes of temperature to which all other existing modes of heating are liable.

Advantages so great would be cheaply purchased at a large increase of expenditure, but the Holly System warms buildings with great uni-

formity of temperature at a cost not exceeding the usual cost of coal.

The apparatus and fittings can be furnished at about half the usual charges for steam fittings, and where buildings are already supplied the ordinary fittings can be used simply by taking steam from the mains and dispensing with the boiler and its excessive waste of fuel; for it has been ascertained by careful tests that the evaporation of such boilers is only four pounds of water per pound of coal, while in properly constructed boilers, on a large scale, with proper firing and attendance, ten pounds of water per pound of coal can be secured as a regular duty. Where houses are supplied with furnaces, it is only necessary to substitute a steam coil in lieu thereof for heating the air; no changes are required in the flues or registers.

Safety is another important consideration. Boilers cannot explode in cellars when they are entirely dispensed with, and houses cannot take fire from stoves, furnaces and defective flues after their use shall have been discontinued.

APPARATUS REQUIRED.

Boilers.—The steam is generated in boilers centrally located, with reference to convenience of procuring coal, the minimum distance of transmission to supply consumers, and the cost of real estate.

The form of boilers should be such as will secure the largest possible evaporation, other things equal, per pound of coal. The President of the Weston Boiler Company claims for it an evaporation 30 per cent. greater than that of any other boiler, and gives the following as the evaporative power per pound of coal:

At a pressure of			10	pounds	(241°)	12	pounds	of	water.
"	"	"	20	"	(260°)	10	"	"	
"	"	"	50	"	(301°)	$8\frac{3}{4}$	"	"	

The evaporation, it must be observed, is not constant at all pressures, but varies with the pressure. Water at 212°, converted into steam at the same temperature, requires 960 units of heat, one pound of steam at 212°, containing sufficient heat to raise $5\frac{1}{2}$ pounds of water from 32° to 212°, and the total number of units above 0 would be 960 + 212 = 1172.

Now if the temperature of the steam and water should be increased, a larger number of units remain with the water, and consequently under

pressures above the atmosphere, the evaporation per pound of coal will be reduced as the pressure increases.

For example: if the pressure should be increased to 10 pounds, corresponding to a temperature of 241°, or $241-212°=29°$, above the boiling point, the one pound of steam must not only be raised in temperature 29 degrees, but the $5\frac{1}{2}$ pounds of water also, and the total units added from water at 212°, will be $6.5\times29+960=1148$, making a total of 1360 units. In like manner, steam at 20 pounds would require $6.5\times48+960=1272$ units, and steam at 50 pounds pressure pould require $6.5\times89+960=1539$ units. Now if the Weston boiler, or other boilers should, as it is claimed, evaporate 12 pounds of water per pound of coal at 10 pounds pressure, the evaporation at 20 pounds should be $1148\times12\div1272=10\frac{8}{19}$, and at 50 pounds $1148\times12\div1539=8\frac{9}{10}$, which is nearly what Weston claims under these pressures.

The Lockport boilers evaporate as their regular daily work 9 pounds of water per pound of coal at 25 pounds pressure, and with careful firing and other precautions, 10 pounds have been secured; but if 12 pounds of water can be evaporated to one pound of coal under 10 pounds pressure, it proves, independently of all other considerations, the immense advantages of concentration of plant over a system of small isolated boilers, whose average duty under careful tests, is proved to be but 4 pounds of water per pound of coal, to say nothing of the dangers of explosion from unskillful or careless attendants, and the annoyance from dust and dirt.

Street Mains.—From the boilers the steam passes into mains laid in trenches, but not covered to so great a depth as is usually required for water and gas pipes, the steam pipes being generally laid above them.

The sizes of these mains depend upon the amount of steam to be supplied, and the distance it is to be carried. The laws which govern the motion of elastic fluids will be discussed, and rules for the determination of dimensions, will be given hereafter.

The material of which the mains are constructed is lap-welded boiler tubes. The largest sizes yet laid have been eight inches, but in introducing the system to large cities, mains of twelve inches or more in diameter will be required.

A twelve inch pipe, one fourth of an inch thick, constructed of iron

of 60,000 pounds tensile strength, would be ruptured by a pressure of 2,500 pounds per square inch, and a safe permanent pressure would be one-fifth, or 500 pounds, but the maximum pressure in the mains from considerations of economy is intended to be about 50 pounds, or only one-tenth of a safe strain, and one-sixtieth of the bursting pressure. The rupture of a street main may therefore be considered impossible.

Protection against Condensation.—The pipes are prepared by placing them in a lathe, in which they can be turned freely, and the coatings as now laid are applied in the following order:

1. Asbestos paper about $\frac{1}{8}$ of an inch thick, one thickness.

2. Coarse brown porous paper, paper roofing felt, such as is used for roofing, before it is saturated with tar, two or three thicknesses.

3. Manilla paper, one thickness, with about two inches lap.

4. Three or four wooden strips, $\frac{3}{4}$ inch broad by $\frac{3}{8}$ inch thick. These strips are wound spirally around the pipes, one turn in about 12 feet, and the whole is securely bound with copper wire wrapped spirally at intervals between the spirals of four inches on pipes of eight inches and upwards in diameter.

These strips leave a space between the iron pipe and the wooden log by which it is enclosed, which allows it to expand and contract freely by changes of temperature, while the logs are securely anchored and immovable.

5. For the outside covering, wooden logs are bored out two inches or more in inside diameter larger than the diameter of the iron pipes, and the thickness of the wooden shell is not less than three to four inches. Pipes of this description are manufactured at Bay City, Michigan, and can be furnished of solid logs, of as large inside diameter as sixteen inches, and at reasonable prices.

The covering of the pipes for the prevention of radiation and condensation has proved remarkably efficacious, and has enabled Mr. Holly to transmit steam to distances far greater than were formerly considered possible. Some changes have been made from the original arrangement, and it is by no means certain that the maximum of efficiency has even yet been attained.

The conducting power of various materials, as determined by the

number of heat units transmitted per square foot per hour by a plate one inch thick, the two surfaces differing in temperature one degree, is:

Copper	515.
Iron	233.
Marble, coarse	22.4
Stone, ordinary	13.68
Glass	6.6
Baked clay, brick	4.82
Plaster, ordinary	3.86
Oak transmitted perpendicular to fibre	1.70
Walnut " " "	.83
Fir " " "	.748
Fir parallel to fibre	1.37
Walnut	1.40
Gutta percha and India rubber	1.38
Brick dust sifted	1.33
Coke, pulverized	1.29
Cork	1.15
Chalk, in powder	.869
Charcoal, in powder	.636
Straw, chopped	.563
Coal, small, sifted	.547
Wood ashes	.531
Mahogany dust	.523
Canvas, hemp, new	.418
Calico, new	.402
White writing paper	.346
Cotton and sheep wool (any density)	.323
Eider down	.314
Grey blotting paper	.274

It appears from an inspection of the above table, from an English author, that the arrangment of enclosing the pipes in a pine log not less than four inches in thickness, is excellent, and cannot be improved upon. Pine wood, when the heat is transmitted in a direction perpendicular to the fibre, is an excellent non-conductor, and, cost considered, perhaps the best possible. It appears, also, that loose materials are much more perfect non-conductors than when solid and compact, as

brick, for instance, which conducts heat $3\frac{1}{2}$ times more rapidly than brick dust. Charcoal, usually considered a superior non-conductor, is not much better than pine wood. Eider down, cotton and wool are nearly equal, and the very best on the list is grey blotting paper. Asbestos is the most expensive article used, and as it is composed chiefly of alumnia, which does not rank high as a non-conductor, baked clay being 4.82, and ordinary stone 13.68, it may be a question whether a cheaper and more efficacious substitute cannot be found. Common paper pulp dry should rank very nearly with grey blotting paper, which is the best non-conductor on the list, and I am informed by a manufacturer and patentee of improved machinery that he can produce this article at a cost of a cent and a half per pound. I would suggest as a substitute for the asbestos and paper coverings a coat of paper pulp half an inch thick, or of such thickness as would make the cost about as at present. I can suggest no other improvement in the mode of protecting the pipes—and even this may not be an improvement—the question can only be settled by a test. If it be considered desirable to retain some incombustible material next to the pipe in case it should be required for the transmission of steam for power at temperatures higher than those at which it is now proposed to use it, a paste of brick dust and coal tar might be a good substitute for the asbestos cloth.

Below the pipes is laid a tile-drain 3 to 4 inches in diameter; boards are placed above and below the pipes daubed with pitch, and the sides are filled with broken stone.

Expansion Joints.—To guard against strains from expansion and contraction caused by differences of temperature, expansion joints are provided.

The extreme limit of expansion may be taken from 32° when the pipes are laid to 311° when filled with steam at a pressure of 60 lbs.

Wrought iron will contract or expand one foot in 151,200 for each degree of temperature, and for $311° - 32° = 279°$, and a maximum length of 200 feet between expansion joints, the extreme variation at any one joint will be $\frac{1}{5\,4\,2}$ of the length, or in 200 feet $= 4\frac{1}{2}$ inches.

The expansion joints are connected with the junction boxes, from which steam is taken to consumers. One end of the main is screwed into one end of the box, and passes through a short distance into the

interior of the box, upon the end of which pipe a sleeve about six inches long is screwed. The free end of the pipe slips loosely into this sleeve, leaving a small annular space through which the steam escapes into the junction box, and thence into the service pipes.

The junction box is a heavy casting, weighing for large pipes several hundred pounds. It is bolted to the brick work and anchored to the logs which surround the pipes, and is intended to be rigid and immovable. The free end of the pipe passes into the junction box and sleeve through an ordinary stuffing box, packed with asbestos packing, which appears to make a perfect joint. The movable end of the pipe is nickel plated and polished for a length of 10 or 12 inches to prevent rust and reduce friction. In large pipes of 8 inches and upward a ball and socket joint is provided to prevent injury or strain from settling at the junction box.

The junction boxes are accessible from the street, being surrounded by a brick wall, upon which is a heavy cast iron cover.

Mr. Holly stated that although these junction boxes had been frequently opened and examined, he had never found any water in them, yet as the process of cooling in the mains is constantly going on, water must be formed; and there is no escape for it excepting through the loose sleeves into the junction boxes.

An explanation will be attempted: Suppose a cubic foot of water at the temperature of steam at 50 pounds=301° should be confined in a non-conducting cylinder, and the piston be moved until the pressure became equal to that of the atmosphere, the temperature of the water would be reduced at once to 212°, and a portion of steam would be formed at the same temperature, the proportions being—

55	pounds	of water	at 212°	contains	55×212=11,660 units.
$7\frac{1}{2}$	"	steam "	212°	"	7.5×960= 7,200 "
$62\frac{1}{2}$	"	water "	301°=		18,860

Now, suppose the water at 212° should be drawn off from the cylinder, leaving the steam containing 7,200 units, and that this steam be compressed to 50 pounds as at first, the temperature would be restored to 301°; but it would not be all steam, for 7.5 pounds of steam at 301° would contain 7.5×(960×89)=7,868 units, while there are only 7,200 units in the steam. A portion of this steam must, therefore,

change its state and become water at 301°, and the amount of this water, determined by calculation, is:

Water	.893 pounds, containing	.893×301°=	269	units.
Steam	6.607 "	"	6.607×(960×89)= 6,931	"
		Making the total units in the steam at 212°=	7,200	

If, now, the pressure be again relieved, the water would return to steam at 212°, on the supposition that no loss has been sustained by radiation, and this process may be continued indefinitely.

It appears, therefore, that steam at 212° can carry 13.5 per cent. more water than steam at 301°.

If, then, the steam in passing through the sleeve into the junction box should be wire drawn so as to make any considerable reduction in the pressure, the water, instead of being deposited, would be absorbed and carried into the service pipes, furnishing moist steam to the consumer, which would be to his advantage. I see, therefore, no reason to apprehend any inconvenience from accumulation of water in the junction boxes, even without the hood provided on the ends of the service pipes, which would effectually remove it if any were present.

Service Pipes.—From the street mains and junction boxes the steam passes into the service pipe, being taken up by a spout called a hood, which turns freely around the end of the service pipe, and is designed when turned downwards to dip into and remove any water that the service box might possibly contain. These pipes will of course be proportioned to the consumption they are intended to supply, and must be carefully protected against loss by radiation.

The mains are not to be tapped, and the service pipes are intended to connect only at the junction boxes.

In populous cities, supplementary small pipes may be required parallel to the mains, with which to connect the service pipes.

These pipes may be laid on each side of a street near the curb, and a small brass cock put in opposite each lot or building, so that if future connections are required they can be made without disturbing the street pavements or shutting off steam from any consumer. Sometimes, also, a single pipe can be carried to the centre of a block, in the rear of all the lots, where a distribution box of cylindrical form will supply all the consumers of that block.

Regulator.—After the service pipe enters a building, carrying steam

at from 25 to 50 pounds pressure, it passes through an apparatus called a regulator, consisting of two diaphragms of rubber packing acted upon by weighted levers, and moving small slide valves by means of rods connected with the diaphragms. The first of these valves reduces the pressure from the mains and service pipes, whatever it may be, to 10 pounds, and the second to five or two pounds, as may be desired for use, depending upon the kind of radiator used for heating the apartments.

It is claimed by Mr. Holly that the regulator will act perfectly with a difference of pressure on the two sides of only one pound, and thus there is no greater difficulty in maintaining uniformity of pressure at the meters, in supplying steam for power and measuring it accurately, than there is in furnishing steam for heat. I see no reason to doubt the assertion, but had no means of testing its accuracy.

Meter.—From the regulator the steam, at a low and uniform pressure, passes to the *meter*, which is always in connection with and operated by the regulator. The meter resembles a yankee clock. It is about 6 inches square on the face and 4 inches deep. When wound it runs for 55 days, and when steam is passing rotates a brass screw with coarse threads on which hangs a pointer moving along a card. Each revolution of the screw registers a unit, and a disc of two inches diameter at the end of the screw registers fractions to hundredths of a unit. The value of the unit has been determined by numerous experiments, said to have amounted to hundreds, the steam passing through having been condensed and weighed. The variation of different meters does not exceed, it is asserted, one per cent.

The meter is operated with a link motion. When the steam is shut off, after passing the meter, the link is on its centre; and although the clock-work continues to move regularly, the index and screw are stationary. When the regulator valve again opens to pass steam the rod connecting the meter therewith moves along the slot in the link, giving a leverage for action, and the screw begins to rotate, and the rotation is the more rapid, as the opening in the valve and the length of the lever are increased. The arrangement is exceedingly simple and ingenious, and Mr. Holly and his son, who is Superintendent of the Lockport Works, both give the most positive assurances, based on their numerous tests, that the indications are reliable. I am not prepared,

however, to endorse this opinion from my own personal observation, and to assert that under all circumstances and all possible conditions the indications of the meter are perfectly reliable. It is probable, however, that if there are errors they may be compensating, and in a month's run the differences may not be material.

I am able to perceive only one condition of things in which the indications of the meter would not be reliable, and that is one the possibility of which is not admitted. If steam should be shut off entirely from the mains, the regulator not being raised by any pressure, would drop to the lowest point, and the pin in the link would be moved with its greatest leverage, and indicate maximum consumption. This would only be possible when the steam was shut off from the mains entirely, which would probably never happen, and if it did, the time could be noted at the office, and a deduction made therefor from the bills of consumers, at the rate of maximum consumption for the time, or another remedy could be provided, which I will venture to suggest.

Between the two diaphragms the steam flows in a pipe at 10 pounds pressure. In this pipe could be placed one of Dickey's reducing valves, or some other, so adjusted as to remain open at say five pounds pressure. If the pressure fell below five pounds, which it never could with steam in the mains, the valve would close, and in closing could throw the pin in the link into the centre, and thus stop recording while permitting the regular movement of the clock-work.

The possibility of steam being entirely shut off from the mains is so remote, and the means of correction if it should occur so simple, that I doubt the expediency of introducing any additional mechanism. It is a satisfaction, however, to know that if the difficulty referred to does exist, a remedy, sure and automatic, is not impossible.

Radiator.—Erom the regulator the steam intended for heating purposes passes into the radiators. Any of the ordinary forms may be used, and all the ordinary steam fixtures, including the indirect, and the air flues can be utilized as perfectly as if steam was generated in a boiler on the premises. If the steam is to be used with ordinary fittings, a pressure of about five pounds is required, but with the Holly radiator, two pounds will be sufficient.

Indirect.—The steam from all the radiators through the building,

together with the water of condensation, passes into a chamber in the basement, and through coils of steam pipe enclosed therein, where fresh air is heated and passed through flues and registers in the ordinary way, to ventilate while assisting to warm the upper apartments.

Traps.—The water of condensation escapes through a steam trap, which opens when the water is at a certain level, and permits it, but not steam to escape. The water from condensed steam being chemically pure, may be, and generally is utilized for domestic purposes.

Other uses of Steam.—An attachment can be made to a steam pipe in any portion of a house, and the live steam used for heating water for bathing, washing, or culinary purposes, the noise of the escaping steam being almost neutralized by the simple device of a small metallic box of tin or brass at the end of the pipe, filled with small fragments of stone.

It has been demonstrated that steam under ordinary boiler pressure, can be used in suitably constructed ovens for baking and roasting, and ovens and stoves have been constructed which operate successfully, as will be seen from my report herewith submitted. Steam for such purposes requires a higher than ordinary temperature and pressure, and a separate meter and regulator for this high steam is necessary. Although this apparatus would not be expensive, some may prefer to use gas or charcoal in the kitchen for roasting or broiling, but for every other purpose low steam would be entirely applicable, and it is probable that a coil of steam pipe in the kitchen, in which the steam could be superheated by gas, would fulfill all requirements for roasting or baking, and allow the extra meter to be dispensed with. For toasting bread or baking batter cakes or waffles, a charcoal furnace would probably be the best and most economical arrangement possible, and then ranges, stoves and furnaces could be dispensed with altogether, and steam fulfill every requirement.

The Holly Radiator.—The most perfect system of warming and ventilating buildings is no doubt the present usual combination of direct radiation and indirect heat and ventilation from a chamber in the basement through air flues, but there are numerous cases where such a system, independently of considerations of expense, cannot be used, as in single offices and often in stores and shops. To supply the place of stoves in such localities, the atmospheric radiator, designed by Mr. Holly, is admirably adapted. This radiator consists simply of

tubes of tin, copper or other material, closed at top and open at bottom. Steam at low pressure is admitted at the top through a simple index valve, and being lighter than air displaces it to any extent that may be found desirable, occupying either the whole of the radiator, or only a few inches at top, according to the temperature. The condensed water runs off through a small pipe, and is not further utilized.

Professional men will find this radiator admirably adapted to their wants. The pipes are painted and bronzed, and are quite ornamental; the space occupied and the cost are trifling, all making of fires and attendance are dispensed with, and the annual cost of fuel greatly reduced.

Radiator Governor.—If in addition to the numerous benefits claimed for the introduction of steam in dwellings and public buildings, there could be an automatic contrivance, which would occupy but little space, would act with certainty, would not be liable to derangement, and would maintain the temperature of an apartment perfectly uniform night and day,—such a contrivance would seem to render the Holly System perfect, and prove a luxury to those in health and a priceless boon to invalids.

I am quite sanguine that this can be accomplished. I find by calculation that a variation of even one degree can be made to move the index valve 90 degrees, which is much more than is required with all extremes of temperature.

By applying the index valve of Holly to the Walworth, and other radiators, the governor could be adapted to any of them.

Having now described as briefly as possible the system of Birdsill Holly, and its mode of application, I now propose to discuss the pneumatic principles involved, and determine the resistances to be encountered, and the losses to be sustained in the transmission of steam to long distances, and furnish rules for the determination of questions in regard to the sizes of mains and service pipes, velocity, consumption, and disposition and size of plant.

DISCHARGE OF FLUIDS THROUGH ORIFICES.

The velocity acquired by a body falling freely in vacuo is eight times the square root of the height, both the velocity and height expressed in feet, and time in seconds.

The velocity of fluids escaping through an orifice follows the law of falling bodies, and is expressed by eight times the square root of the height, in feet.

This result is not practically correct, as the discharge is less than would be due to the full area of the orifice. The particles in escaping reduce the diameter by contraction of vein to .8, and the area to about .64 of the full area of the orifice.

In the case of elastic fluids the density of a vertical column would diminish from the bottom to the top, and the height, in estimating the volume of discharge, must be taken as that of a column of uniform density, the height of which would be equal to the pressure at the orifice.

Where the discharge is made into a receiver containing the same fluid at a reduced pressure, the differences in pressure must be taken in determining the height and velocity.

A remarkable exception to this law has been announced in a work on steam, published in London, 1875, by D. K. Clark, in which it is stated that the application of the formula for gravity is limited to cases in which the resisting pressure does not exceed about 58 per cent. of pressure which causes the flow. The flow is neither increased nor diminished by reducing the resisting pressure below about 58 per cent. of the absolute pressure in the boiler. For example, the same *weight* of steam would flow from a boiler under a total pressure of 100 pounds to the square inch, into steam of 58 pounds total pressnre, as into the atmosphere.

The author states that for this remarkable discovery he is chiefly indebted to the experiments made by Mr. R. D. Napier, and refers to a report on safety valves made to the Institution of Engineers and Ship-Builders in Scotland in 1874.

Desiring to obtain further information on this subject, I requested Prof. Geo. W. Plympton, editor of Van Nostrand's Engineering Magazine, to see if he could find, in the libraries in New York, the report on safety valves referred to. A letter has just been received in reply, in which he states that he found the report at the rooms of the Society of Civil Engineers, but that it merely quoted the deductions of the experimenter, Napier, in the same form as previously given. Prof. Plymp-

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&001 08-13408
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&100 Haupt, Herman, 1817-1905.
&245 Report upon the system of the Holly steam combination company limited,
of Lockport, N.Y.,
&260 Lockport, N.Y., Union printing and publishing company, 1879.
&300 84 p. 23 cm.
&650 Heating from central stations.
&710 Holly steam combination company limited, Lockport, N.Y.

ton also states that Rankine discussed the same subject, and that Napier contributed articles to "Engineering" on this topic in 1772.

If the conclusions of Napier be accepted as correct, it would appear that steam escaping from an orifice into the air at a pressure of 25 pounds, acquires a velocity of about 800 feet per second, and attains a maximum of 875 feet, after which the velocity remains constant, however great the pressure. Some direct experiments on the velocity of steam escaping from an orifice, just completed by Messrs. Holly and Gaskill, of Lockport, give, in one case, 951 feet per second, and in another, 1023 feet per second. These experiments were made with great accuracy.

It is not difficult to uuderstand that the *velocity* might be constant, for the velocity is that due to the height of a column of uniform density, whose weight is equal to the pressure. Now, if the pressure should be doubled, the density and weight of a uniform column would also be doubled, and the height which determines the velocity would remain constant; but the declaration that the *weight* of steam discharged remains constant, requires confirmation.

The efflux of steam through an orifice fortunately has but little influence on the discharge through long pipes where the velocities are comparatively low, and the results will not be effected by any uncertainties in regard to the velocity of flow through orifices.

RESISTANCE OF LONG PIPES TO THE FLOW OF ELASTIC FLUIDS.

This is one of the most important subjects connected with the practical and extended application of the Holly System, and it is one upon which comparatively little information can be obtained from books. Mr. Holly states that he has searched in vain for any reliable information on the subject, and the only table I have found published, is headed "friction of air, steam and gas in long pipes," without any recognition of the influence of density, which would cause the results to vary in the wide range of from 4 to 10. I propose, therefore, to give this subject a careful consideration.

When engaged in maturing plans for tunneling the Hoosac mountain, I made a series of experiments in the friction of air in a tunnel at Wicinisco. A pipe of wood was constructed about 1400 feet long and

110 square inches in area. The current of air was produced by a vacuum fan, driven by a steam engine, the velocities determined by an electrical apparatus, and the results demonstrated

1. That the resistance was in proportion to the square of the velocity.

2. That the resistance was inversely as the diameter.

3. That the power required to pass a given quantity of air through pipes of different diameters was inversely as the fifth powers of the diameters. As a consequence it was found that it would require a million times more power to pass the same quantity of air through a pipe one foot in diameter, than would be required if the pipe were 10 feet.

At the Mt. Cenis Tunnel it was decided to use compressed air as a motor, and the preparatory experiments were made at government expense by a commission of gentlemen of eminent scientific attainments, consisting of Messrs. DeNerache, Giulio, Minabeia, Rura and Sella.

Special experiments were instituted on long lines of metallic pipe, continued by rubber hose, and observations made on pressure and velocity. The elastic force of the fluid was ascertained at the commencement and end of the pipe, and a curved traced for the interpretation of the results, from which a table was prepared, giving initial velocities in metres per second, diameters of pipes in decimals of a metre, and friction or loss of tension in millimetres of a column of mercury.

A copy of the report of this commission was procured for me through the kindness of Professor Gillespie; from it I calculated a table in which pressures were expressed in pounds, velocities in feet per second, and lengths in miles.

In using tables for the friction of elastic fluids through pipes one peculiarity is observable. With dense fluids, such as water, the head is an important element in calculating the loss by friction, but with elastic fluids the initial velocity is given, and the head is not a necessary datum in the calculations where there is a free discharge; but when there is back pressure it would seem that the initial density, as also the initial velocity, must be considered.

The explanation is this: Suppose pressure should be quadrupled, the fluid being supposed perfectly elastic would be quadrupled in density, and the power required to move it at a given velocity, which

measures the resistance, would be quadrupled also, or would be as 1 to 4; but the velocity being as the square root of the head or pressure, would be doubled also by quadrupling the head or pressure, and would be as 1 to 2, and the resistance would be as $(1)^2 : (\frac{1}{2})^2$, or $\frac{1}{4}$. Hence, while the increase of density would quadruple the resistance, the reduction of velocity due to that pressure would reduce it to one-fourth, or the resistance of a given length with a given velocity would be constant.

This conclusion may be reached by another process of reasoning: Where a fluid is discharged through a long pipe the pressure at the commencement is the head in the reservoir; at the end where it discharges it is nothing, or simply the head due to the velocity. The hypothenuse of a triangle, of which the base represents the length and the perpendicular the head, will be the hydraulic gradient, and so long as head divided by length or hydraulic gradient is constant, the velocity is constant and the discharge also. Now, if head should be quadrupled, velocity remaining constant, length must be quadrupled also, and head divided by length, which represents the friction per unit of length will be constant also, and will vary in the same pipe with the square of the velocity.

In determining the resistance of elastic fluids, density is an important element, which appears sometimes to have been overlooked. That it is important will be obvious from the consideration that the power required to move a body is in proportion to the weight of the body moved, and the weight is in proportion to density; if density should be doubled the resistance will be doubled, and if reduced the resistance would be reduced proportionately.

Let us imagine two elastic fluids of equal height, but whose densities compare as 1 to 2. As the heights are equal the velocities of discharge will be equal. On a line as above, representing a unit of length, draw a perpendicular 1 and complete the triangle; draw a second perpendicular 2 and complete the second triangle. The perpendiculars at any point will represent the pressure at that point, and the areas of the triangles will be proportioned to the total resistance. As these areas compare as 1 to 2, so will the loss by friction be as 1 to 2, or as the densities.

DEMONSTRATION OF THE LAW OF THE DISCHARGE OF ELASTIC FLUIDS THROUGH LONG PIPES.

The quantity of steam discharged through a pipe of a given length and diameter under a given pressure, and the losses by friction and radiation, are questions which lie at the very foundation of the successful application of the Holly System, and without which it will be impossible to form plans and prepare estimates for the supply of any given district with confidence that mistakes will not be committed, that the plans provided will not prove insufficient, and that mains will not require to be torn up or duplicated after the lesson has been learned from dearly bought experience that sound theory should have taught in advance.

As it has been found impossible to procure from any known authors on hydraulics or pneumatics just that practical information that will meet the requirements of the present investigations, and as the writer has ventured to enunciate a fundamental law on which the solution of all problems relating to steam transmission must depend, and which is not only not contained in books, but is in conflict with rules given by popular authors, no apology will be necessary for the time and space devoted to a demonstration of the law in question. This law may be thus enunciated.

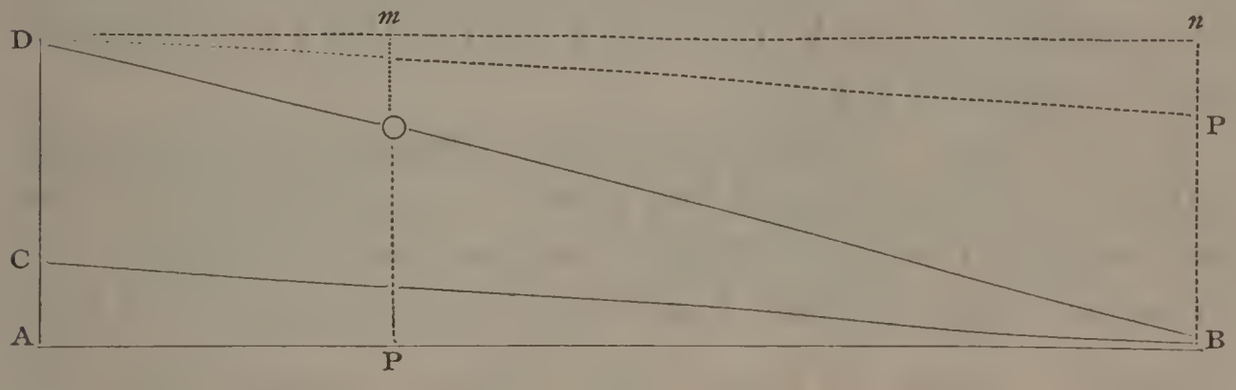
The discharge of steam, air or any elastic fluid, under pressure through long pipes and at the volume due to atmospheric tension, is equal to the water discharge under like conditions, multiplied by the square root of the number which expresses the relative density at atmospheric tension, as compared with water, multiplied also by the square root of the initial pressure in atmospheres.

For example, air is 836 times lighter than water under ordinary atmospheric tension, and if n=number of atmospheres of initial pressure, then the water discharge, as determined by the usual formula, multiplied $\sqrt{836}=29$ multiplied by $\sqrt{n}$, will give the discharge of air; and if the discharge of steam is required the multiplier will be $\sqrt{1712}=42\times\sqrt{n}$.

If, then, n should be 4 atmospheres *total*, including atmospheric pressure, the difference of head to be used in the determination of the water discharge would be 3 atmospheres, and water discharge $\times 42\times\sqrt{4}$=water discharge$\times 84$=discharge of steam.

In like manner, if the total pressure should be 9 atmospheres=120 pounds indicated pressure, the discharge of steam would be=water discharge$\times 42\sqrt{9}=126$ times the water discharge under an equal head.

And, in general, if w=the water discharge under any given head, length and diameter of pipes, d=ratio of density of any elastic fluid, as compared with water and at the volume due to atmospheric tension, and n=number of atmospheres of initial pressure, then will the discharge, as compared with water, and at the volume due to atmospheric tension, be$=w\times\sqrt{n\ d.}$



Let A B represent a pipe of any given length, say one mile, and A C represent the pressure, say 60 pounds. The discharge of water at B, in cubic feet per second, is given by the formula:

$$G=.0762\sqrt{d^5}\sqrt{\frac{H}{L}}$$

d=diameter in inches, H=head in feet, or the difference in head when discharging against a lower pressure, and L=length in feet.

If A C=60 pounds, the head of water would be $60\times 2.31=138.6$ feet, and the discharge with a constant length would be as$\sqrt{H}$, or as $\sqrt{138.6}$, and the area of a triangle of which A B is the base and $\sqrt{138.6}$=the altitude, would be proportionate to the water discharge—or A B$\times\sqrt{138.6}$.

Now suppose that the fluid discharging at B should be steam instead of water under 60 pounds indicated pressure, the actual pressure would be 75 pounds, the number of atmospheres 5. The initial density five times that of steam under atmospheric pressure, or $\frac{1712}{5}=342$, and the head due to a pressure of 60 pounds$=138.6\times 342=47{,}401$ feet.

The discharge being proportioned to the square root of the head, would be as $\sqrt{138.6\times 342}$, or as $\sqrt{138.6}\sqrt{\frac{1712}{5}}$ and if A B as before

=base of a triangle, and 47401=altitude, the discharges being as the square root of the altitude, will be as the area of a triangle whose base is A B and altitude $=\sqrt{47401}=\sqrt{138.6}\times\sqrt{1712}\div\sqrt{5}$.

The water discharges and steam discharges being as the areas of these triangles having the common base A B, will compare, as $\sqrt{138.6}$ is to $\sqrt{138.6}\sqrt{1712}\div\sqrt{5}$, or if the water discharge be taken as unity, then as 1 is to $\sqrt{1712}\div\sqrt{5}$.

But this expression gives the discharge under initial density, and if the discharge is required at atmospheric tension, which is always desirable for the sake of uniformity, the result must be multiplied by 5, and the expression becomes $\sqrt{1712}\times 5.\div\sqrt{5}=\sqrt{1712}\times\sqrt{5}$, as previously stated, or generally as $\sqrt{n\ d.}$

The head due to velocity has not been considered, as in questions relating to discharges through long pipes, it is so insignificant as compared with the head due to friction, that it may safely be neglected. It would not exceed, generally, a small fraction of a pound; but if great accuracy is desired the head, in feet, is readily determined, and is $\frac{v^2}{64}$ in which v=initial velocity, and the head divided by the number of feet at initial density required to make one pound, will give the pressure in pounds required for this velocity v, which is in addition to friction. Suppose the length of the pipe should be increased, and draw a line from D to the end of the pipe, intersecting the line n B at P. The triangle D n P will be cut off, the perpendiculars, of which will represent the loss of head by friction, and the square root of the area, the discharge in cubic feet, and the same rule holds good if the length should be less than A B.

Important Observation.—Although almost self-evident yet, as very erroneous ideas seem to have been entertained in regard to the friction of pipes, it is necessary to state, emphatically, that in the discharge of fluids through pipes—whether the fluids be elastic or non-elastic—the *whole* of the head, less that due to velocity is absorbed by friction; and where there is a free discharge there is no pressure whatever at the open end of the pipe.

Referring again to the diagram, if A B is a pipe a mile long and discharges water, steam or air freely at B under an initial pressure at A= 60 pounds, there will be no indicated pressure whatever at B unless the

discharge be throttled, and the reduction of pressure from A to B will follow the line of the hypothenuse, and the pressure at any point will be represented by the perpendiculars. If, for example, the initial pressure be represented by A D, the pressure at B will be *o*, the total loss of pressure by friction in the distance A B will be 60 pounds. At any point P the pressure will be represented by the perpendicular O P, and the loss of pressure by O *m*.

But if the pipe is not discharging freely at B, the conditions will be very materially changed, and a large percentage of the fluid may be drawn off at intermediate points without affecting very seriously the pressure at B, due to the initial head if the pipe were closed.

It has been asserted as the result of observation that at Detroit a mile of pipe 6 inches in diameter was laid, and notwithstanding the fact that a large number of consumers were using steam at intermediate points, the pressure at the boiler and at the end was precisely the same; and the inference deduced therefrom was that steam can be carried almost any distance with a loss of power that is scarcely appreciable.

This is a great mistake, and it would be a fatal error if works were planned and constructed with any such ideas. If the observed pressures at the two ends of the pipe at Detroit were the same, it resulted from two causes: First, a want of sensitiveness in the gauges, which often do not indicate within ten pounds of the correct pressure; and second, the intermediate consumers were drawing off a small percentage of the capacity of the pipe.

I will endeavor to elucidate this subject by a simple and practical illustration:

Suppose a pipe be taken 6 inches diameter, one mile long, and 60 pounds initial pressure. The water discharge will be 1.1 cubic feet and the steam discharge $=1.1\sqrt{1712}\times\sqrt{5}=102$ cubic feet of steam per second.

A horse-power is one cubic foot of water evaporated per hour, and one cubic foot of water $=1712$ cubic feet of steam. Therefore, $1712\div 3600=.472$ cubic foot per second $=$ one horse-power.

And $102\div.472=216$ horse-power $=$ maximum capacity of 1 mile of 6-inch pipe under 60 pounds pressure.

But suppose the end B of the pipe is closed, and at the point P $=\frac{1}{4}$

of a mile from A, one-fourth of the whole capacity of the pipe is drawn off, how will the pressure at B be affected?

If discharging freely at B, the pressure at P, at $\frac{1}{4}$ A B, will be $\frac{3}{4}$ of 60 pounds, or 45 pounds, and the loss of pressure will be represented by O $m=15$ pounds. But if the end B is closed, and the discharge at P is $\frac{1}{4}$ capacity of pipe, then the velocity from A to P will be reduced to $\frac{1}{4}$, and the friction, which is as the square of the velocity to $(\frac{1}{4})^2=\frac{1}{16}$, and the loss of head from taking off 25 per cent. of the whole capacity of the pipe at P, would be $15\times\frac{1}{16}=\frac{15}{16}$ of one pound, and the pressure at B would be $59\frac{1}{16}$ pounds as compared with an initial pressure of 60 pounds.

If one-half the whole capacity of the pipe should be drawn off at the middle point, or if there should be an equivalent thereto discharged the reduction of pressure at the extreme end, instead of being 30 pounds, or one half, would be $\frac{60}{2}\times(\frac{1}{2})^2=7\frac{1}{2}$ pounds, and the pressure remaining would be $52\frac{1}{2}$ pounds.

These results, deduced from purely theoretical considerations, seem to be entirely consistent and reasonable, but it is important to test them by actual and careful experiments.

The experiments of Mr. Holly and Mr. Gaskill at Lockport were made under circumstances peculiarly favorable to accuracy. A large engine cylinder was used as a meter; the contents, including clearance, were 8.64 cubic feet; the number of cylinders discharged per minute, 66; cubic feet per minute, 570; distance from boiler equivalent to 168 feet of 2-inch pipe in frictional resistance; boiler pressure, 50 pounds; cylinder pressure, 30 pounds; loss by friction, 20 pounds.

From these data let us determine the friction in one mile of 6-inch pipe under a head or pressure of 60 pounds.

If Mr. Holly gets a discharge of 570 cubic feet per minute in a pipe 2 inches diameter and 168 feet long, the discharge per second will be $570\div60=9.5$, under total initial pressure of $50+15=65$ pounds; as the discharge is in proportion to square root of length, the discharge in one mile $=9.5\times\sqrt{\frac{1680}{5280}}=1.78$ cubic feet.

If the discharge is 1.78 cubic feet in a 2-inch pipe, the discharge being as the square root of the fifth power of the diameter, it will be in a 6-inch pipe $1.78\times15.6=27.76$. If the discharge be 27.76, under 30 pounds, and under initial pressure of 50 pounds, the discharge at

atmospheric tension under initial pressure of 60 pounds, would be $27.46 \times \frac{30+15}{15} \times \sqrt{\frac{60}{50}} = 91.6$ cubic feet per second, as deduced from experiment of Messrs. Holly and Gaskill through a pipe obstructed by several bends.

We will now examine what should have been the discharge through a pipe one mile long, six inches diameter, under 60 pounds head as deduced from the theoretical law heretofore enunciated.

The water discharge is 1.1 cubic feet per second, and $1.1 \times \sqrt{1712} \times \sqrt{\frac{60+15}{15}} = 102$, the theoretical discharge, and the difference, 10.6 is fully explained by the eight bends in the pipe through which the steam was transmitted in the experiment.

This result giving a greater theoretical than actual discharge, is the more gratifying because it has generally been believed that theory was unreliable, and that the actual results as deduced from observation and experiment were far in excess of the capacity and pressure as given by the books.

This is true, because in stating a rule the books did not always state the conditions under which it was applicable, as for example the rule that the discharge of air is equal to $30\frac{1}{4}$ times the discharge of water under like conditions, is true only at one initial pressure, and that a very low one, while under high pressures the error from its application may be several hundred per cent.

If theory is not sustained by observation and experiment, it only proves that the theory is defective, and that the true law has not been discovered; but that there are natural laws is unquestionable, and these laws, as applicable to pneumatics, are as immutable as those of gravity.

Practical men proceeding without a knowledge of these laws, are like mariners at sea without chart or compass.

I propose to show that the law of discharge that has been here given is further verified by the careful and elaborate experiments made at the Mt. Cenis tunnel.

FRICTION OF AIR IN PIPES AS DETERMINED FROM THE EXPERIMENTS AT THE MT. CENIS TUNNEL.

The scientific commission, appointed to conduct these experiments, reported the following table as a condensation of their results:

Loss of tension per 1000 *metres of pipe expressed in millimetres of a column of mercury.*

Velocity of air at the entrance of the pipe, in metres, per second.	Diameter of pipes in the clear, in decimals of a metre.					
	0.10	0.15	0.20	0.25	0.30	0.35
1	6	4	3	3	2	2
2	26	18	13	11	9	8
3	62	42	31	25	21	18
4	108	72	54	44	36	31
5	167	112	84	67	56	48
6	233	156	117	94	78	67

An inspection verifies these laws:

1. Friction inversely as diameters.
2. Friction directly as squares of velocities.

To which may be added two other laws:

3. Friction directly as the length.
4. Friction directly as the density.

In comparison with other results the friction of 1 mile of 6-inch pipe with initial velocity, 20 feet will be deduced from this table.

Assume any number, say a pipe .2 of a metre diameter and 5 metres velocity, the loss in millimetres of mercury is 84.2 of a metre=7.874 inches; 5 metres per second=16.4 feet; 1000 metres=3281 feet; 1 millimetre=.03937 inches.

Then $84\times\frac{7.874}{6}\times\frac{20^2}{16.4^2}\times\frac{.03937}{2}\times\frac{5280}{3281}=5.1$ pounds, as the resistance of air, and for steam 2.5 pounds per mile, assuming loss of tension to be in proportion to density.

We will now apply the law as deduced from the hydraulic discharge:

The discharge of water under a head of 60 pounds, length 1 mile and diameter 6 inches, is 1.1 cubic feet per second.

Air is 836 times lighter than water. 60 pounds$=\frac{60+15}{15}=5$ atmospheres; $1.1\times\sqrt{836}\times\sqrt{5}=67.87$ cubic feet per second, and at initial density$=67.87\div5=13.57$ cubic feet, and initial velocity 68 feet per second, nearly.

Now, if the loss of tension with initial velocity of 68 feet be 60 pounds, the loss with velocity of 20 feet will be $60 \times \frac{20^2}{68^2} = 5.1$ pounds.

This is precisely the loss of tension in one mile of 6-inch pipe discharging air under an initial velocity of 20 feet per second, as deduced from the experiments of the Mt. Cenis Tunnel commissioners.

The law of discharge, above stated, seems to be completely verified and established, both by the experiment in Europe and those made by Mr. Holly at Lockport with the engine metre, and I think can be safely relied upon as a basis of calculation of capacity of mains and losses by friction in transmission.

The following table will be convenient, giving the discharge of steam at the volume of atmospheric tension, the corresponding water discharge under same head, diameter and length being taken as unity, and pressures varying by half atmospheres from 1 to 10:

Pressure in Atmospheres.	Initial Densities.	Volume of Discharge.
1	1712	41.4
1½	1141	50.7
2	856	58.6
2½	685	65.5
3	571	71.7
3½	489	77.3
4	428	82.8
4½	381	88.2
5	342	92.5
5½	311	97.3
6	285	101.4
6½	263	105.9
7	245	109.6
7½	228	113.2
8	214	117.0
8½	201	120.5
9	190	124.1
9½	180	127.7
10	171	130.8

TABLE OF THOMAS BOX.

In the valuable work on heat by Thomas Box, is given a table for the friction of air, steam and gas in long pipes. The difference in

density is not recognized in this table, but it was probably intended for air, as this fluid was more particularly under discussion. Under this hypothesis, the results will be compared with our assumed standard of velocity, 20 feet, length one mile, diameter six inches.

The table gives the head to overcome friction with velocity of 10 cubic feet per minute through a two-inch pipe for a distance of one yard =.000162 pounds.

Area of 2-inch pipe =3.1416 and $10\times\frac{144}{3.1416\times 60}=.77$=velocity in feet per second.

$.000162\times 1760=.285120$=friction per mile in 2-inch pipe.

$.285120\times\frac{2}{6}=.09504$=pounds per mile friction in 6-inch pipe, velocity .77.

$.09504\times\frac{20^2}{.77^2}=6.3$=friction of air in a 6-inch pipe for a distance of one mile and velocity 20 feet per second.

The friction of steam at atmospheric density should by the same rule be 3.15 pounds, which is in excess of the results deduced from formula, from the Mt. Cenis experiment, and from other experiments.

FORMULA OF WEISBACH.

Weisbach gives the following formula for the friction of air through long pipes:

$f=.0256\times\frac{l}{d}\times\frac{v^2}{2g}$ in which

l=length in feet;

d=diameter in feet;

v=velocity in feet per second;

f=height of a column of air equal to the resistance by friction.

To test this formula, assume length=1 mile, diameter 6 inches or .5 of a foot, and v=20 feet. Then friction of one mile represented by a column of air equals $.0256\times\frac{5280}{.5}\times\frac{20^2}{64}=1700$ feet.

But 1700 feet of air, if at atmospheric tension, would be equivalent to about two feet of water, weighing less than one pound, while from other data, both theoretical and experimental, it is known that the friction is five pounds. If the initial, instead of the terminal density is intended to be used, the difficulty is that there is no way given for the determination of this density, and the formula, even if correct, is practically useless.

So also the rule of the engineer's pocket-books, that the discharge of air is 30½ times the discharge of water under like conditions, is entirely fallacious. It can be true only at one pressure, and that a very low one, and it fails to recognize the varying densities of elastic fluids under varying pressures, without which no rule can be reliable.

PIPES OF EQUIVALENT RESISTANCES.

When a line of pipe consists of portions whose diameters are not uniform, it is necessary to make a correction by substituting the length of pipe of uniform diameter that would give an equivalent resistance.

It has been stated that where quantity is constant and diameter variable the friction is inversely as the fifth power of the diameter.

If the friction in one mile or one unit of length of one-inch pipe be taken as unity, the number of miles of pipe of any other diameter will be given by the following table, giving equal resistance:

1	inch pipe	1.
1½	"	7.5
2	"	32.
2½	"	97.65
3	"	243.
4	"	1024.
5	"	3125.
6	"	7776.
7	"	16807.
8	"	32768.
9	"	59049.
10	"	100000.
11	"	161051.
12	"	248832.

FORMULA FOR CALCULATING TABLES OF LOSS OF HEAD BY FRICTION.

It has been seen that in the transmission of steam through a pipe six inches in diameter and one mile long the loss by friction was 2.5 pounds, with an initial velocity of 20 feet per second.

For any other length we have these laws:

1. The friction is as the length.
2. The friction is inversely as the diameter.
3. The friction is as the square of the velocity.
4. The friction is as the density.

As a basis of calculation, it will be convenient to determine the friction of steam in 1 mile of 1-inch pipe, with an initial velocity of one foot per second.

The friction in 1 mile of 6-inch pipe, and initial velocity 20, being 2.5 pounds with steam, the friction in a pipe 1 inch in diameter will be $2.5 \times 6 = 15$ pounds under the same velocity; and the friction with a velocity of 20 feet per second being 15 pounds, the friction with a velocity of one foot per second will be $15 \times \frac{1}{20^2} = .0375$.

For any other diameter or velocity the expression becomes:

Friction per mile $= .0375 \times \frac{v^2}{d}$.

The initial velocity must be determined from the discharge, and the terminal discharge, as previously stated, is = water discharge $\times \sqrt{1712} \times \sqrt{n}$, in which n = the atmospheres of pressure. This discharge divided by n gives discharge at initial density, and the discharge at initial density in cubic feet divided by the area in square feet will be initial velocity.

TABLE OF LOSS BY FRICTION FOR STEAM IN POUNDS PER SQUARE INCH FOR ONE MILE OF PIPE, WITH INITIAL VELOCITIES AS GIVEN IN THE FIRST COLUMN IN FEET PER SECOND, AND DIAMETER OF PIPES FROM ONE TO 12 INCHES.

Velocity in Ft. per sec.	DIAMETER OF PIPES IN INCHES.													
	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12
5	.9375	0.625	.468	.375	.312	.2344	.1875	.156	.134	.117	.104	.094	.085	.078
10	3.75	2.50	1.875	1.50	1.25	.937	.75	.625	.535	.468	.42	.375	.341	.312
20	15.0	10.0	7.5	6.0	5.0	3.75	3.0	2.50	2.14	1.87	1.66	1.50	1.36	1.25
30	33.75	22.50	16.87	13.5	11.25	8.44	6.75	5.62	4.82	4.22	3.75	3.37	3.07	2.86
40	60.0	40.0	30.0	24.0	20.0	15.0	12.0	10.0	8.55	7.5	6.66	6.00	5.46	5.00
50	93.75	62.5	46.87	37.5	31.25	23.44	18.75	15.62	13.4	11.72	10.42	9.37	8.52	7.81
60	135.0	90.0	67.5	54.0	45.0	33.75	27.0	22.5	19.3	16.87	15.0	13.5	12.3	11.25
70	184.0	123.	92.0	73.6	61.3	46.0	36.8	30.0	26.3	23.0	20.4	18.4	16.7	15.3
80	240.0	160.	120.	96.0	80.0	60.0	48.0	40.0	34.3	30.0	26.6	24.0	21.8	20.0
90	304.0	203.	152.	121.6	101.3	76.0	60.8	50.6	43.4	38.0	33.7	30.4	27.6	25.3
100	375.0	250.	187.5	150.0	125.0	93.7	75.0	62.5	53.6	46.8	41.6	37.5	34.1	31.2
125	586.0	391.	293.	234.4	195.3	146.5	117.2	97.0	83.7	73.2	65.1	58.6	53.3	48.8
150	843.0	562.	421.	337.2	281.0	210.7	168.6	140.5	120.4	105.3	93.6	84.3	76.6	70.2
175	1148.	765.	574.	459.1	382.6	287.0	229.6	191.3	164.0	143.5	127.5	114.8	104.4	95.6
200	1500.	1000.	750.	600.0	500.0	375.0	300.0	250.0	214.3	187.5	166.6	150.0	136.3	125.0
250	2343.	1562.	1172.	937.2	781.0	585.7	468.6	390.5	334.7	292.8	260.3	234.3	213.0	195.2
300	3375.	2250.	1687.	1350.	1125.	843.7	675.0	562.5	482.1	421.8	375.0	337.5	307.0	281.2
350	4593.	3062.	2296.	1837.	1531.	1148.	918.6	765.5	656.1	574.	510.3	459.3	417.6	382.7
400	5000.	3333.	2500.	2000.	1666.	1250.	1000.	833.0	714.3	625.	555.5	500.	455.5	416.5

For any other diameters or velocities observe:

1. The friction is as the square of the velocity.
2. The friction is inversely as the diameter.

3. The friction is directly as the length.
4. The friction is directly as the density.

CAPACITY OF MAINS AND VELOCITY OF STEAM.

The discussions in the preceding pages will indicate a simple manner of obtaining the discharge of any elastic fluid through pipes, and, as a consequence, its velocity when the diameter is known. It is only necessary to calculate the water discharge under the same length, diameter and pressure, and multiply the result by the square root of the number expressing the relative density, multiplied by the square root of the number of atmospheres of initial pressure.

The limit of velocity is found in the discharge through an orifice, or short pipe of not more than two diameters, and appears from the experiments of Messrs. Holly and Gaskill to attain its maximum at about 1000 feet per second, between which and zero the velocity will vary with pressure, diameter and length.

Assuming a maximum effective pressure of 60 pounds per square inch in the mains, the water discharge in a six-inch pipe 100 feet long will be, per second: cubic feet $=.0762\sqrt{6^5\times\frac{60\times 2.31}{100}}=7.85$ cubic feet, and $7.85\times\sqrt{1700}\times\sqrt{s}=7.85\times 41.3\times 2.24=726$ cubic feet, and $726\div.2\times 5=726=$initial velocity of the steam on entering the pipe.

If the length of pipe were 1000 feet the discharge and the velocity would be reduced in proportion of $\sqrt{\frac{100}{1000}}$ or $\frac{726}{3.17}=229$ feet per second.

The general formula for the discharge of steam is, in cubic feet per second, at atmospheric density.

$c=.0762\sqrt{d^5}\times\sqrt{\frac{H}{L}}\times 41.3\times\sqrt{p}$; or $c=31.47\sqrt{d^5}\times\sqrt{\frac{H}{L}}\times\sqrt{p}$, in which $d=$diameter in inches.

H=head, in feet, of water.

L=length in feet.

$p=$density in atmospheres.

If it be found most convenient to express the pressure in pounds, instead of feet, of water, the constant 31.47 will become 47.73, and H will then represent pounds of effective pressure.

The following table, calculated from the above formula, will facilitate computations on the capacity of mains for the transmission of steam, and the same table may be used for air by multiplying by $\sqrt{\frac{836}{1712}}=\frac{289}{414}=\frac{3}{4}$, nearly:

Diameters inches.	Square root of 5th powers.	Area of pipe in square feet.	DISCHARGES OF STEAM IN CUBIC FEET PER SECOND FOR A LENGTH OF 100 FEET, AT ATMOSPHERIC DENSITY, UNDER INITIAL PRESSURES IN POUNDS OF										
			5	10	15	20	25	30	35	40	45	50	55	60
1	1	$\frac{1}{183}$	1.235	1.948	2.637	3.274	3.899	4.561	5.183	5.692	6.420	7.036	7.661	8.320
1½	2.74	$\frac{1}{81.5}$	3.384	5.337	7.251	9.003	10.723	12.542	14.254	15.653	17.655	19.349	21.067	22.880
2	5.66	$\frac{1}{45.8}$	7.000	10.039	14.883	18.552	26.093	25.846	29.370	32.255	36.380	39.871	43.411	47.147
2½	9.88	$\frac{1}{29.3}$	10.979	17.318	23.443	29.106	34.652	40.567	46.077	50.602	57.074	62.550	68.106	73.965
3	15.6	$\frac{1}{20.3}$	19.266	20.389	41.137	51.074	60.824	71.151	80.855	88.795	100.14	109.76	119.51	129.79
3½	22.9	$\frac{1}{14.9}$	27.40	44.58	60.39	74.97	89.27	104.4	118.7	130.4	147.0	161.1	175.4	190.5
4	32.0	$\frac{1}{11.46}$	39.68	62.40	84.16	104.64	124.8	145.9	165.8	172.1	205.4	225.3	245.1	266.2
4½	43.0	$\frac{1}{9.08}$	53.11	83.74	113.4	140.7	167.6	196.1	222.9	244.8	276.0	302.5	333.7	357.7
5	55.9	$\frac{1}{7.33}$	69.03	108.8	147.4	187.2	218.0	255.0	289.8	318.2	358.9	393.3	434.9	466.1
6	88.2	$\frac{1}{5.09}$	108.9	171.8	232.6	288.7	343.9	402.3	457.2	502.2	566.3	620.6	684.6	730.9
7	129.7	$\frac{1}{3.74}$	160.2	252.6	342.0	424.5	505.6	591.5	672.3	738.3	832.6	912.5	1007.	1079.
8	181.0	$\frac{1}{2.86}$	223.5	352.6	477.4	592.4	705.7	825.5	938.3	1031.	1162.	1284.	1405.	1506.
9	243.0	$\frac{1}{2.25}$	300.1	473.3	640.8	795.3	947.4	1108.	1260.	1383.	1560.	1710.	1886.	2032.
10	317.	$\frac{1}{1.85}$	391.5	617.5	836.0	1038.	1236.	1446.	1643.	1805.	2035.	2230.	2461.	2638.
11	401.	$\frac{1}{1.52}$	494.	779.2	1054.8	1309.	1559.	1824.	2073.	2277.	2568.	2814.	3064.	3328.
12	499.	$\frac{1}{1.273}$	617.	974.	1318.	1637.	1949.	2280.	2591.	2846.	3210.	3518.	3830.	4160.

For any other length than one hundred feet, divide the numbers in the table by the square root of the length in feet, and multiply by ten.

For discharges at initial densities, divide the numbers in the table by the pressures in atmospheres.

For initial velocities, divide the discharge at initial density by area in square feet, the quotient will give feet per second.

LOSS OF STEAM BY CONDENSATION.

The only data on this subject applicable to the solution of the practical and economical questions presented for our consideration are derived from the experiments and observations of Mr. Birdsill Holly. To him is due not only the credit of the grand conception of utilizing steam at great distances from the point of generation, but also of the details of protection and the mechanical contrivances by which such utilization became possible.

Preparatory to any discussion of this portion of the subject, a statement of some of the experiments, which furnish necessary data, will be given, and they will be numbered consecutively for convenience of reference:

Experiment No. 1.

Forty feet of 6-inch pipe, 400 feet of 4-inch pipe and 1,600 feet of 3-inch pipe were connected; steam blown through to expel the air; the end closed; 60 pounds steam at boiler, admitted until pipe was filled; then shut off and allowed to cool down to the temperature of the atmosphere. The pipes were protected as hereinbefore described.

The time required to condense the four atmospheres was as follows:

From 60 to 45 pounds	.....	18 minutes.
" 45 to 30 "	.....	28 "
" 30 to 15 "	.....	40 "
" 15 to atmosphere	.....	54 "

Experiment No. 2.

A pipe 1,600 feet long and 3 inches diameter was laid on a descending grade of 20 feet in the 1,600. The lower end was provided with a trap, which permitted water, but not steam, to escape. The pressure was nearly constant at both ends of the pipe—about 20 pounds. The condensation water, accurately weighed, was 82 pounds per hour, rep-

resenting 9 pounds of coal or $2\frac{1}{4}$ per cent. The duration of the experiment was 12 hours. The condensed water 31.2 cubic feet in 24 hours.

Experiment No. 3.

Test on condensation from radiators. Square feet of radiating surface, 40.

The water from the condensed steam per hour was:

At atmospheric pressure	13.25	pounds.
" 10 pounds "	17.25	"
" 15 " "	18.00	"
" 25 " "	20.25	"

Previous tests indicated that condensation doubled with an increase of 30 pounds pressure. Tests, at different times, did not give uniform results.

ADDITIONAL DATA DERIVED FROM OBSERVATION AND EXPERIMENT.

Experiment No. 4.

One cubic foot of steam is allowed to heat one cubic foot of space for 16 hours per day.

Experiment No. 5.

A test made in the winter with 32 pounds pressure, instead of 25, increased loss by condensation in 3-inch pipe, 10 per cent.

Experiment No. 6.

The loss from condensation alone in small steam boilers, used for heating purposes, is from 40 to 60 pounds of coal per day, to hold 10 pounds of steam, and not draw any out. Proved by careful tests.

Experiment No. 7.

The evaporation of the small boilers for heating purposes is only four pounds of water per pound of coal.

Experiment No. 8.—Amount of Radiator Surface required for heating.

One square foot of steam radiator surface to 100 cubic feet of space in well protected situations.

One square foot of radiator to 60 cubic feet in exposed situations.

One square foot of radiator to 250 cubic feet in large churches and similar buildings.

Experiment No. 9.

Steam through coil heating water, communicates 335 units of heat per square foot per hour for each degree of Fahrenheit.

Experiment No. 10.

The indirect for heating air in basement, contains an upper and a lower coil of inch pipe, each of which requires $3\frac{1}{2}$ lineal feet for each 150 cubic feet in the building which it ventilates and warms.

DISCUSSION OF EXPERIMENTS.

No. 1 gives the relative time of cooling from four atmospheres. The temperature at a pressure of four atmospheres, (60 pounds indicated,) is 307°; at three atmospheres, 294°; at two atmospheres, 275°; and at one atmosphere, 250°.

A cubic foot of water converted into steam contains $62.5 \times 1172 = 73250$ units, and $73250 \div 1728 = 42$ units of heat in one cubic foot of steam at 212°. If five cubic feet be compressed into one, the contained units will be $42 \times 5 = 210$.

The first 42 units was	condensed in	18	minutes,	=2.33	per	minute.
The 2d "	"	"	28	"	1.50	"
The 3d "	"	"	40	"	1.05	"
The 4th "	"	"	54	"	0.80	"

These numbers are in the ratio of 100, 131, 187, 291.

The differences which express the loss of units are 31, 56, 104, or nearly twice as many heat units are lost in a given time under a pressure of 60 pounds and temperature 307°, as under 45 pounds and 294°.

But the quantity discharged, or the capacity for transmission, varying as the square root of the pressures, is as the numbers 11.77 at 60 pounds, 10.19 at 45 pounds, 8.33 at 30 pounds, and 5.9 at 15 pounds, and the differences in heat units at these pressures will be represented by

$5.9 \times 250° = 1475.$

$8.33 \times 275° = 2291.$

$10.19 \times 294° = 2996.$

$11.77 \times 307° = 3613.$

Or in proportion as 100, 155, 203, 244.

While therefore pressures of 15, 30, 45, and 60 pounds result in losses of heat units represented by 100, 131, 187, 291, the capacity for carrying heat units increases as 100, 155, 203, 244. At 60 pounds it appears that the increase of loss by radiation is somewhat greater than the increased capacity for transmission of heat units, which would seem to indicate that a pressure of 60 pounds is a proper economic limit.

To determine from Experiment No. 1 the percentage of loss.

Suppose the steam to be transmitted to a distance of 1 mile through a three-inch pipe, to the limit of its capacity. The temperature of 60 pound steam is 307°, and the loss per cubic foot of steam per minute has been given at this temperature as 2.33 units.

A cubic foot at atmospheric density would occupy 20 feet in length, and at the density of five atmospheres, four feet in length.

The cubic feet in one mile of three-inch pipe would be $5280 \div 4 = 1320$, and the heat units lost by cooling would be $1320 \times 2.33 = 3080$.

The capacity of a three-inch pipe one mile under 60 pounds pressure discharging at atmospheric density is $.0762 \times \sqrt{3^5} \times \sqrt{60 \times 2.31} \div \sqrt{5280} \times \sqrt{1712} \times \sqrt{5} = .0762 \times 15.6 \times 11.7 \div 72.7 \times 41.3 \times 2.24 = 20$ cubic feet per second, or 1200 cubic feet per minute at atmospheric density, equivalent to 240 cubic feet under five atmospheres. As one cubic foot occupies a space of four feet, 240 cubic feet would occupy a space of $240 \times 4 = 960$ feet, and $5280 \div 960 = 5.5$ minutes for the time of passage one mile.

Now if one cubic foot loses 2.33 units of heat per minute, 240 cubic feet $\times$ 5.5 minutes $\times$ 2.33 = 3080 units loss per mile per minute in the three-inch pipe.

But the capacity being 1200 cubic feet per minute, $1200 \times 42 = 50400$ units, and the loss is therefore 6 per cent. per mile in a three-inch pipe, nearly.

The capacity of a six-inch pipe as compared to a three-inch pipe is 5.66 to one, and its radiating surface two to one. The proportionate condensation in a six-inch pipe should be 2.1 per cent., and in a 12-inch pipe about one per cent.

Discussion of Experiment No. 2.

As the 1600 feet of pipe were laid on a descending grade, the water

of condensation, 82 pounds per hour, should represent accurately the number of heat units lost by condensation.

The pressure being 20 pounds at both ends, the temperature was 228°.

The heat units in each pound of steam above 212°=960.

The heat units lost in 82 pounds per hour condensed, were 82×960 =78720, and per minute 1312. The capacity of a three-inch pipe 1600 feet long per minute in steam at 20 pounds pressure is in cubic feet at atmospheric tension $.0762\times\sqrt{3^5}\times\sqrt{\frac{20\times2.31}{1600}}\times41.3\times60\times\sqrt{\frac{35}{15}}$ =765 cubic feet per minute.

62.5÷1700×765=28 pounds. 28×966=27044 heat units per minute transported through the three-inch pipe, and as 1312 units were lost per minute, the percentage of loss in 1600 feet of three-inch pipe would be 4.8. As compared with one mile of six-inch pipe we would have relative capacity under equal pressure 1 to 5.66; relative radiating surface 2 to 1. Then $4.8\times\frac{2}{1}\times\frac{1}{5.66}\times\frac{52}{16}\frac{80}{00}=5.5$ per cent. for condensation in one mile of 6-inch pipe as against 2.1 per cent. deduced from experiment No. 1.

In a 12-inch pipe, as compared with a six-inch pipe, the capacity is as 499 to 88, and the radiating surface as 2 to 1. The percentage of loss in a 12-inch main should therefore be 1.8, if worked to its capacity.

Experiment No. 3.

Forty square feet of radiating surface condensed, say 15 pounds of water in an hour, at ordinary pressure of 5 to 10 pounds in radiator; 15 pounds of water in steam contain above 212°; 15×966=14490 units of heat=$\frac{14490}{40}$=362 units per hour per square foot of radiator.

The specific heat of air, as compared with water, is 0.2377.

To raise 1 pound of air from 32° to 70°=38°, will require 0.2377× 38=9 units.

One pound of air=13 cubic feet at 60°.

One square foot radiating surface would raise from 32° to 70°, 362 ×13÷9 cubic feet of air per hour=524 cubic feet, assuming no loss by radiation or openings, raised in one hour from 32° to 70°.

The usual allowance is from 60 to 250 cubic feet per foot of radiating surface, according to exposure and other conditions.

A consumer with 12,000 cubic feet of space, and 80 cubic feet per

square foot of radiating surface, would require 12,000÷80=150 square feet radiator surface, and 150×362=54,300 heat units per hour, or 54,300÷3,600=15 units per second.

The capacity of a 6-inch main under 60 pounds pressure will be, in one mile, $.0762\times\sqrt{6^5}\times\sqrt{\frac{60\times2.31}{5280}}\times41.3+\sqrt{5}=103$ cubic feet of steam, and 103×42=4329 units per second.

Deduct loss by condensation in one mile of 6-inch pipe, $5\frac{1}{2}$ per cent. =237 units, leaves available 4089 units, and 4089÷15=273 consumers supplied by a 6-inch pipe at a distance of one mile on this basis.

But, if one cubic foot of steam be allowed to one cubic foot of space for 16 hours, the 6-inch pipe at an average distance of one mile would supply 500 consumers.

If it be assumed that one pound of coal evaporating 9 pounds of water furnishes an average of 1000 available heat units per pound after deducting condensation, then one pound of coal represents 9000 heat units, and a consumer with 150 square feet radiator, using heat 16 hours, would represent pounds of coal per day 150×362×16÷9000 =96 pounds, or 6 pounds per hour, at a cost of $1\frac{1}{2}$ cents per hour at $5 per ton for the whole building, containing an average of 6 ordinary apartments, well heated, assuming inside temperature 70° and outside 32°. This is much more than average consumption.

Experiment No. 4.

One cubic foot of steam will heat one cubic foot of space 16 hours.

One cubic foot of steam contains of available heat units 62.5×1000 ÷1700=37.

One pound of air raised from 32° to 70° required 9 units.

One pound of air is 13 cubic feet.

One cubic foot requires .7 of a unit.

Thirty-seven units would heat the cubic foot of air from 32° to 70° 50 times in the 16 hours, and if the apartment was protected from drafts should be much more than sufficient. Experience in such matters is the only safe guide. Mr. Holly's data are, he claims, based on observation and tests. On the basis of one cubic foot of steam to heat one cubic foot of space for 16 hours, 12,000 cubic feet of space would require 12,000×42=504,000 heat units, representing 56 pounds of coal instead of 96, as deduced from No. 4.

Experiment No. 5.

A winter test of condensation made probably in the same manner as former ones, by the weight or measure of condensed water, gave 10 per cent. more condensation at a pressure of 32 pounds than a former test gave at 25 pounds.

Observation.—The discharges were as $\sqrt{32} : \sqrt{25}$, or as 5.6 : 5. The condensation was increased in the same proportion as the increased discharge, and, consequently the percentage measured by heat units transmitted was nearly constant.

Experiment No. 6.

If 40 to 60 pounds, say average 50 pounds, of coal, are lost daily in simply keeping up the fire without drawing out any steam, this amount of coal would, at the station properly used, produce $50 \times 9 \div 62.5 \times 1{,}700 = 12{,}440$ cubic feet of steam, capable of warming a house of average consumption 16 hours. All this heat is, on the old system, entirely wasted; or, expressed in other terms, the waste on the old system is equal to the whole average consumption on the new.

Experiment No. 7.

The evaporation of four pounds of water to one pound of coal in small boilers, as against the regular duty of 9 pounds at the station, shows that the actual heat units utilized in warming a building on the old system require $2\frac{1}{4}$ times the coal, as compared with the Holly System, in addition to the 50 pounds of coal lost per day by condensation, as stated in No. 7.

Observations 8, 9 and 10 require no comment; they furnish data for estimates.

Observation.—It appears from experiments discussed that $5\frac{1}{2}$ per cent. for a distance of one mile in a six-inch main will be sufficient to cover losses by condensation when transmitting steam to the limit of the capacity of the pipe, and there are no other losses where steam is used for warming buildings. Although the condensation is greater at 60 pounds pressure and temperature of 307°, measured by the number of units condensed, yet, as the units transmitted are greater, the percentage of loss is nearly constant.

In pipes of other diameters it may be assumed as practically correct that the condensation is inversely as the diameter.

From experiment No. 1 it appears that the loss of heat units from one cubic foot of steam per minute will be

At 60 pounds,	307°,	2.33,	or per hour	139.
" 45 "	294°,	1.50	"	90.
" 30 "	275°,	1.05	"	63.
" 15 "	250°,	0.80	"	48.

As the pipe was three inches in diameter, 20 feet were required to contain one cubic foot, presenting 16 square feet of radiating surface, and it follows therefore that the loss of heat units per square foot of radiating surface will be

At 60 pounds	8.7
" 45 "	5.6
" 30 "	4.0
" 15 "	3.0

A one-inch service pipe, carrying steam at 30 pounds, and for a distance of 100 feet will lose by condensation $26.2 \times 4 = 105$ units per hour. Its carrying capacity under this pressure will be $.0762 \times \sqrt{\frac{30 \times 2.31}{100}} \times 41.3 \times \sqrt{3} \times \sqrt{42} = 196$ units per second. 196 units per second $= 196 \times 3600 = 705600$ units per hour.

A consumption of 12000 cubic feet of steam at 212° in 16 hours, equivalent to one cubic foot of steam for each cubic foot of space, is equal to 750 cubic feet per hour, and $750 \times 42 \div 3600 = 8.7$ units of heat per second which is only one twenty-second of its capacity. The loss by condensation is $\frac{1}{3}$ of 1 per cent. in 100 feet from these data.

The condensation in 100 feet of service pipe will in this case amount to .33 of one per cent. on the consumption which it supplies, or at the rate of 17.6 per cent. per mile.

Condensation in Pipes of Different Diameters.—With the same pressure and length the capacities for transmission vary directly as the square roots of the fifth powers of the diameters, while the radiating surface increases only in proportion to the diameters. If therefore the loss in one mile of six-inch main be taken at $5\frac{1}{2}$ per cent. of the heat units transmitted, the percentage of loss in a pipe of one inch would be $5.5 \times 88 \div 6 = 80$ per cent. of the heat units transmitted one mile discharging at the limit of capacity.

For a 2-inch pipe the percentage would be $80 \times 2 \div 5.66 = 29.0$ per cent.
" 3 " " " " $80 \times 3 \div 15.6 = 15.4$ "
" 4 " " " " $80 \times 4 \div 32 = 10.0$ "
" 5 " " " " $80 \times 5 \div 56 = 7.1$ "
" 6 " " " " $80 \times 6 \div 88 = 5.5$ "
" 7 " " " " $80 \times 7 \div 130 = 4.3$ "
" 8 " " " " $80 \times 8 \div 181 = 3.5$ "
" 9 " " " " $80 \times 9 \div 243 = 2.9$ "
" 10 " " " " $80 \times 10 \div 317 = 2.5$ "
" 11 " " " " $80 \times 11 \div 401 = 2.2$ "
" 12 " " " " $80 \times 12 \div 499 = 1.9$ "

It appears therefore that in large mains the percentage of loss by condensation is trifling, and in service pipes it would appear desirable that the diameter should be as small as possible consistent with a full supply, that a fair velocity may be maintained, and that radiating surface in proportion to units transmitted be reduced as low as possible.

TRANSMISSION OF HEAT BY WATER AND CAPACITY OF MAINS AS COMPARED WITH STEAM.

Water, in consequence of its great capacity for heat, can be made the vehicle of transmission of a large number of heat units, but this advantage is neutralized to a great extent by the fact that its density causes it to move with low velocity; and, if returned for reheating, as the advocates of the system propose, a double line of pipes will be required, which will largely increase the cost beyond the proportionate increase of capacity.

Suppose that a three-inch hot water main could transport as many units of heat in a given time as a six-inch steam main, the water main must be doubled by the return pipe, and the cost of pipes and laying, as appears from an inspection of Mr. Holly's tables, based on actual cost, would be precisely equal, independently of the expense of pumping back into the boiler, so that nothing could be gained on the score of economy of plant.

To compare the two modes of transmission, it would be fair to take as a basis equal capital invested, and allow a three-inch main for hot water and a six-inch main for steam, the cost of the two being equal; but the comparison will first be made with mains of equal size, and the

question considered with reference to units of heat transmitted, and the cost at which they can be furnished to the consumer for the portion actually utilized.

WHAT IS THE HOT-WATER SYSTEM?

As explained by its advocates in the newspapers, it consists in providing a boiler in which water is heated to the temperature of 350 pounds pressure, then transmitted through pipes, converted into steam at a pressure of from 1 to 50 pounds per square inch, as may be desired, and returned to the boiler by means of a pump to be reheated. "It is stated that the power can be used to drive machinery; that the most obvious advantage, as compared with steam is, that the hot water weighs $62\frac{1}{2}$ pounds per cubic foot, while steam of the same temperature weighs only a few ounces; hence, a vastly greater number of units of heat may be conveyed by water in the same-sized pipe."

These declarations will be submitted to the test of calculation, it being remembered that it is only the number of units of heat *capable of being utilized* that can be estimated; units of heat traveling around a circle and pumped back into the boiler cannot accomplish anything useful, but must involve expense and loss of power in transmission.

Assume a pipe six inches in diameter and one mile long. The hot water returned at 212° and pumped back into the boiler, the excess above 212° being supposed to be utilized for heating purposes.

The water discharge under 350 pounds pressure, and distance one mile, will be $.0762 \times 88 \times \sqrt{\frac{350 \times 2.31}{5280}} = 2.6$ cubic feet per second.

The steam discharge at the same pressure at the boilers will be 528 cubic feet, and the velocity of the steam 203 times greater than water. But the water must be returned to the boilers, and must travel two miles, while the steam travels one; this will reduce the discharge in the proportion of $\sqrt{2}$ to 1, and the 2.6 feet will become 1.85 cubic feet relative velocity 1 to 285. The temperature of water or steam under 350 pounds pressure is 431 degrees.

If the water be supposed under conditions most favorable to the system to be returned to the boiler for reheating at 212°, the greatest number of heat units that could by any possibility be utilized would be $1.85 \times 62.5 \times 219^{\circ} = 25320$ units per second, but this amount is largely in excess, for if the whole of the water were returned $\frac{350}{2} = 175$ pounds

pressure on the return main, would be required to send it back to the boiler, and the units in the return pipe are not utilized, but allowing that steam has been used, and only the water due to a pressure of 120 pounds is returned, the quantity utilized can be determined. $1.85 \times 62.5 \times 431^{\circ} = 49832$ units per second. The temperature at 120 pounds is 346°. Now for 100 pounds of water reduced in temperature from 431° to 346° by reduction of pressure, there would be liberated, as shown by calculation, ten pounds steam at 346°, leaving 90 pounds water at same temperature.

This ten per cent. of steam, omitting losses by radiation, is all that can by any possibility be utilized, and if the condensed water be allowed to flow off, for it cannot be returned to the boiler without pumping against the pressure in the mains, the total units of heat per second capable of being utilized will be 10,000, assuming 1000 units per pound.

The steam pipe would carry 528 cubic feet, each cubic foot containing 42 units, and $42 \times 528 = 22176$ units, all of which would be utilized.

The relative capacity for transportation of available units would therefore be as 22176 to 11.560, or as 1 to 2.22 in favor of steam.

But it must be remembered that this difference is simply in capacity of mains, and not in cost, which is the practical question. It requires precisely as many pounds of coal to produce a given number of units of heat in hot water as in steam, and if the water pipe carried a greater number of available units, which it does not, it must be remembered that it has required a proportionate number of pounds of coal to produce them. There is clearly no advantage is reducing size of mains, if that reduced size is secured at increased cost, particularly when it is considered that for each cubic foot of contents the radiating surface in the small pipe is increased in proportion to the difference of the diameters. For example a six-inch pipe requires five feet in length to contain a cubic foot of volume and presents $7\frac{1}{2}$ square feet of radiating surface, while a three-inch pipe requires 20 feet in length for a cubic foot, and the radiating surface is 15 square feet, and with return main 30 feet or 4 to 1 against the hot water pipe.

Omitting considerations of condensation the true practical basis of comparison would be capacity of mains in proportion to cost and as a three-inch water main with return costs when laid precisely as much as

a single six-inch steam main, the relative capacities will be compared.

These capacities are in the proportion of the square root of the fifth powers of the diameters, or as 1 to 5.66, and if the six-inch pipe transported 10,000 available heat units per second, the three-inch pipe could carry only $10{,}000 \div 5.66 = 1767$, against 22176 units carried by a steam main laid at the same cost, giving an advantage of more than 12 to 1 in favor of steam, on the only point upon which the advocates of hot water claim superiority. Clearly the capacity to transport a greater number of heat units cannot be claimed to be of value if these units cannot be utilized.

We have now considered the conditions most favorable to the hot water system. In other important particulars the advantages are overwhelmingly in favor of steam. The objections to hot water as a vehicle of transmission other than those already stated, are

1. The double loss by condensation from the necessity of having a return main.

2. It is generally supposed that the water of condensation from the heat utilized by consumers is to be returned into the boiler through the return main; this is impracticable. If the mains are connected at the extreme end, as will be necessary to cause circulation, the pressure on the return main at the commencement will be half the boiler pressure, less pressure due to water or steam used, and it will be impossible without a pump at each building, to return the condensed water into it. In fact the condensation from all the heat utilized must be wasted, none of it can be returned.

3. The portion of water that can be returned to the boiler by means of a pump is only that which remains as water when the pressure is reduced to 15 pounds, and the temperature to 212°.

4. To pump this water back into the boiler against a pressure of 350 pounds will require an amount of power represented by coal which will exceed the whole amount required to heat the water originally.

5. To force the water back through the return main will cause the loss of another large percentage of power and coal.

6. To waste the water and not return it, would be to waste a large percentage of the heat generated.

7. It seems impossible to utilize the hot water system in any way

without the expansion joints, junction boxes, and other appliances and combinations that are covered by the Holly patents.

8. To use hot water as a fuel to generate steam in other boilers is impracticable, and if practicable would not be economical.

9. To use the steam liberated from hot water by reduced pressure as a power, is less economical than to use the steam directly from the mains or to generate it in the usual manner.

These propositions will be more fully considered:

1. The double loss by condensation in the double line of pipes is obvious and requires no explanation.

2. There must necessarily be a heavy pressure on the return main, which is required to bring the water back to the boiler to be reheated. If no water had been wasted or steam consumed, this pressure at the commencement of the return main would have been one-half the initial pressure, or 175 pounds, but if ten per cent. be utilized in steam and 90 per cent. returned to the boiler, the pressure required to return it will 141 pounds.

3. The portion of water that can returned to the boiler under the conditions assumed is ninety per cent. of the quantity forced from the boiler, or $1.88 \times .90 = 1.665$ cubic feet per second, with a velocity of 8.325 feet per second in a six-inch pipe.

4. The area of a six-inch pipe is 28 square inches, and the pressure to be overcome in pumping the water back into the boiler is 350 pounds per square inch, or $28 \times 350 = 9800$ pounds. The velocity being 8.325 feet per second, or 500 feet per minute, the power required to pump this water back, with usual allowance of 33 per cent. for friction, will be 225 horse power. The power expended at the boiler in circulating the water when it started on its course was 165 horse power or the coal required to pump the water back against the assumed pressure of 350 pounds is greater than the coal required to generate the heat proposed to be utilized.

This fact should be obvious without any calculation, for if the water returned to the boiler with its force expended, it would require as much power to return it, as was required to put it in circulation, independently of friction of machinery, but this friction would increase it 33 per cent, if the quantity returned was the same; and the quantity returned must be the same, because any steam or water lost in trans-

mission must be replaced by other water pumped into the boiler against the same pressure.

5. The pressure required in the return main has been shown to be 141 pounds, and the only office performed by it, is to return a portion of the water to be pumped back, at a cost of fuel greater than the whole expenditure for heating the water originally.

6. If the water is allowed to run off and is not returned, the steam above 212° only being utilized, there will be a loss of 23,380 units in the water, and the steam will carry 45,120 units, the loss being 33 per cent. of the heat units generated.

7. The hot water system cannot be applied without junction boxes, expansion joints, regulators, meters, and their combinations with each other, and with mains, all of which, as also the use of hot water in mains, are covered by the steam combination patents.

8. The heat of an ordinary furnace is from 1,500 to 2,000 degrees. The rapidity of the transmission of heat is in proportion to the difference of temperature. To heat water, and then use this hot water as fuel to heat other water to nearly the same temperature, would require an enormous extension of boiler surface and increased loss by radiation. It would be an exceedingly slow operation, and could not compare favorably in ecomomy with direct generation in the usual manner. The amount of heating surface required with a given difference of temperature could be calculated, and the expense as compared with direct steam estimated, but time and labor would be thrown away—the proposition is clearly economically impracticable.

9. No doubt hot water at a high temperature can be carried in pipes, and steam produced at a lower temperature by reduction of pressure, but the water must either be allowed to run off at a high temperature, carrying a very large amount of the heat with it, or if returned to the boiler, will require a larger expenditure of power than all that was secured by the use of the steam, or it must be used as hot water in heating indirect coils, which is practicable, and this use of hot water is as previously stated, contemplated in the Holly System, but not the return main and pumps, the paternity of which Mr. Holly is not particularly anxious to claim.

I have not considered the increased loss by condensation and radiation from the high temperature at which hot water is proposed to be

utilized, equivalent to more than 24 atmospheres. The loss between atmospheric pressure and one atmosphere being assumed as one unit, the loss from two to one was shown to be 1.3 units, from two to three atmospheres 1.9 units, and from three to four atmospheres nearly three units. The difference increases with the pressure and temperature, and at four atmospheres is three times as much as at one. At 24 atmospheres the loss by radiation and condensation would be greatly increased, and this would be doubled by the return main.

In conclusion, I will state as my deliberate opinion in regard to the hot water project that a more absurd and impracticable scheme for transmitting heat and furnishing power never entered the mind of man. And in this discussion I have omitted other very serious objections, such as the great liability to explosion under 350 pounds pressure, as compared with steam at 60 pounds. I feel however that I have already given the subject more time and space than it merits.

COMPARATIVE COST OF WARMING AN AVERAGE BUILDING OF 12,000 CUBIC FEET OF SPACE, ON THE HOLLY SYSTEM AND ON THE ORDINARY SYSTEM, WITH SMALL BOILER IN BASEMENT.

On the Holly System.—12000 cubic feet of space requires 12000 cubic feet of steam for 16 hours.

One pound of coal will evaporate 9 pounds of water. 9 pounds water give 9×1000 units available heat, 9000. One cubic foot of steam contains 42 units. 9000 units give $\frac{9000}{42} = 214$ cubic feet. 1000 cubic feet require $\frac{1000}{214} = 4.7$ pounds of coal. 12000 cubic feet require $12 \times 4.7 = 56.4$ pounds of coal 16 hours. At $5 per ton coal costs $\frac{500}{2000} = \frac{1}{4}$ cent per pound.

56.4 pounds cost per day of 16 hours	.14
A year of 200 days, 14×200	$28.00
Loss by condensation, 4 per cent	1.12
	$29.12

On the Old System.—Evaporation 4 pounds water to one of coal.

Cost of 12000 cubic feet steam per day, $14 \times \frac{9}{4}$	$0.32
Radiation from small boiler per day, 50 pounds average of coal, as per tests made for the purpose, $50 \times \frac{1}{4}$	0.12.5
	$0.44.5

For 200 days	$89.00
Interest and repairs on boiler and other extra fixtures	21.00
	$110.00

The interest on cost of works has not been considered, but only the consumption in a dwelling. The expense of interest on capital must be divided amongst the whole number of consumers.

Estimates of plant and capacity of a six-inch main, to supply consumers of heat alone, at an average distance of one mile, under a boiler pressure of three atmospheres—45 pounds.

The capacity of the main for water is .956 cubic feet per second, and for steam 79.34 cubic feet.

The water evaporated per hour will be $79.34 \times 3600 \div 1700 = 168$ cubic feet $= 168$ horse power. The number of consumers supplied will be for 16 hours, $79.34 \times 3600 \times 16 \div 12000 = 383$.

Cost of plant:

3 boilers of 75 horse power each	$ 3,600
Building and lot	2,000
One mile 6-inch main laid	12,000
20,000 feet service pipes laid	14,000
Capital invested	$31,600

Cost of operation:

2800 cubic feet water per day $= 2800 \times 7 = 19600$ coal, $5	$49 00
2 firemen	3 00
Per day,	$52 00
Fuel and attendance 200 days	$10,400
Clerk and book-keeper	500
Collector and inspector	500
Treasurer and President	2,000
Repairs	1,500
Annual expenses	$14,900

Income:

383 consumers at $100	$38,300
Deduct expenses	14,900
Surplus	$23,400

Sufficient to cover expenses and 73 per cent. on capital.

The estimate would apply to a small village of about 1000 to 1500 population. As the population becomes more dense, the proportionate cost of plant and general expenses will diminish, and the ratio of net revenue increase.

It is proper to observe that this estimate is low on an average of $100 to each consumer, which would be slightly increased if the small boilers to generate steam were properly protected against radiation, and it assumes also that any consumer will gladly pay the cost of fuel to get rid of the danger from boiler explosion, the dirt of coal and ashes, the expense of attendance, and the numerous annoyances and discomforts of the present system. With furnaces, the dirt, waste and expense are believed to be still greater, but no accurate data are at present accessible. $100 per average house is probably a fair estimate of cost of fuel and its attendant expenses for heating, and if steam can be furnished at the same cost, it seems fair to assume $100 as a basis of an estimate.

ESTIMATE OF COST OF WARMING ONE MILE SQUARE IN A LARGE CITY.

In estimating the amount of space we will assume 30 feet high and 100 feet deep on each side of each street=6000 cubic feet of space for each lineal foot of street.

Allow ten streets, and deduct 25 per cent. for cross streets and walls, there will be 240,000,000 cubic feet to be heated, and requiring for 16 hours as many cubic feet of steam=147060 cubic feet of water=9191 cubic feet of water per hour. $9191 \times 7 = 64337$ pounds of coal per hour, or 1029420 pounds per day, or for 200 days 100,000 tons of coal and a boiler capacity of 9600 horse power, with small reserve.

The quantity of steam to be furnished being, in 16 hours, 240,000,000 cubic feet, is equivalent to 4,166 cubic feet per second.

Assume for purposes of illustration merely, and not as an economical arrangement, that the boiler station is located at one corner of the square, that the mains are carried along one side, and then laid along each of the ten streets, and that at the commencement of each street the pressure on the mains shall be 40 pounds. The solution of this problem will give an illustration of the manner of procedure in other cases. Assume also that the square mile has ten cross streets. There will then be 100 blocks to be warmed. The street mains can furnish

steam to a distributing point in the centre of each block. Each of the 10 street mains must then supply one-tenth of 240,000,000 cubic feet = 24,000,000 cubic feet, and this would be reduced one-tenth at intervals of 500 feet, where the service pipes would be taken off. The capacity of the street mains for the first 500 feet would be twenty-four millions of cubic feet per day, or say 416 cubic feet per second, and as the principal main is supposed to be on one side of the block, a table of the discharges can be readily given.

TABLE OF CAPACITIES REQUIRED FOR STREET MAINS.

For	First	500 feet.....	500	feet per second.
"	Second	"	450	"
"	Third	"	400	"
"	Fourth	"	350	"
"	Fifth	"	300	"
"	Sixth	"	250	"
"	Seventh	"	200	"
"	Eighth	"	150	"
"	Ninth	"	100	"
"	Tenth	"	50	"

We may assume for the first section the diameter of main that would be required if the whole amount of 500 cubic feet per second, under 40 feet head, were to be carried for the whole distance of one mile, and then determining the pressures at the junctions of the supply pipes for the several blocks, reduce the size of the main so as to maintain the same pressure in each section with the reduced discharges that would have existed if the whole amount had been carried to the end. The size of the main required to pass 500 cubic feet per second, under 40 pounds pressure, is obtained from this formula. The cubic feet per second discharged $=.0762\sqrt{d^5}\times\sqrt{H}\times 42\times\sqrt{\frac{5}{1}\frac{5}{5}}\div\sqrt{L.}$ With a pressure of 40 pounds H = 92.4 feet, and L = 5280. The formula works out $d = 13$ inches, the required diameter.

Instead of one main of 13 inches to each street, it may be considered preferable to lay two smaller mains of equivalent capacity, one near each curb, and the size required will be two of ten inch, as the equivalent of one of 13 inches,—the capacity being as the square root of the fifth power of the diameter.

The capacity of a 12 inch main one mile, under a head of 40 pounds, will be 406 cubic feet per second, and as the close calculation without margin was 416 cubic feet, a single 12 inch main will probably be sufficient, particularly if a connection is made so as to provide a circuit.

If we have a given head of water, and a given diameter and length of pipes, the quantity discharged can be calculated with certainty, and neither more nor less will go through the pipe under a constant pressure. Steam follows the same laws, and under a constant head, and length, and diameter of pipe, the quantity discharged is also fixed, and an equal or greater amount cannot be passed through a smaller pipe without increase of pressure.

Assuming, then, a 12 inch main, an initial pressure of 40 pounds, and length one mile, the pressure of 40 pounds would be reduced 4 pounds at each of the service junctions, and the quantities would also be reduced by the escape of one-tenth of the whole number of cubic feet at each junction, so that a table of pressures and discharges would be as follows: The discharge of a 12 inch main under 40 pounds at one mile being 406 cubic feet,

1st	section	500	feet,	pressure	40	pounds,	discharge	406	cubic	feet.
2d	"	500	"	"	36	"	"	365	"	
3d	"	500	"	"	32	"	"	324	"	
4th	"	500	"	"	28	"	"	283	"	
5th	"	500	"	"	24	"	"	242	"	
6th	"	500	"	"	20	"	"	201	"	
7th	"	500	"	"	16	"	"	160	"	
8th	"	500	"	"	12	"	"	119	"	
9th	"	500	"	"	8	"	"	78	"	
10th	"	500	"	"	4	"	"	37	"	

The above table shows the distribution of the street supply, and the sizes of pipes in each street vary from 12 inches to 6 at the last 500 feet, if not connected in a circuit, but such connection is always desirable.

There remains to be considered the sizes of the principal mains to carry the steam from the boiler house to the street mains. The boiler house supposed to be at an angle of the square.

As there are ten street mains, carrying at the start 4166 cubic feet

per second, and requiring a capacity of 10 twelve-inch mains, under varying pressures. After passing 500 feet, the number of mains would be reduced to 9, and after the next 500 feet to 8, until only one would be required to supply the most distant of the ten streets.

The pressure on these mains will not be equal. It has been assumed that the pressure on the distributing mains will be uniformly 40 pounds. To give this pressure at the last street, will require a boiler pressure of 80 pounds, reducing for each street 4 pounds, until first from the boilers, which will require 44 pounds.

To fulfill these conditions practically, will require separate nests of boilers to supply the steam for each street, and one street will require for 406 cubic feet per second, $406 \times 42 \times 3600 = 61,387,200$ heat units per hour $= 64,000$ pounds of water evaporated per hour, or 1000 cubic feet per hour, or 1000 horse power for each street of one mile in length. Each battery must therefore contain 12 boilers of 80 horse power each, and 120 boilers will be required to furnish steam for the mile square.

The mains leading to the several streets will require expansion joints but not junction boxes, and one intermediate expansion joint between streets would probably be sufficient, for which a more simple and economical arrangement than the ordinary junction box can probably be devised.

The ten mains, if laid side by side, would occupy too much space in the street. They might be laid two abreast and five high at the start. At the first street one of the upper mains would curve off; at the second street another of the first tier would come off, leaving four tiers, which, in the next 500 feet, would rise nearer to the surface, and at the extreme end the depth of the trench would not exceed the usual depth for a single main.

Laid in this manner, the trench would not be inconveniently wide, and the number of pipes in close proximity would aid in preventing loss by condensation.

Of course it will be discerned that the problem presented is hypothetical. It is doubtful whether any square mile in American cities will require 240,000,000 cubic feet to be heated, and the location for the boiler house, instead of being at one corner, might be in the centre. A case has been assumed as the only way to indicate clearly how to make the estimates and furnish an illustration of the great expansion

of main capacity and boiler power when large areas are to be supplied at long distances from the boilers.

It will be apparent from the discussion of this practical question that the ideas heretofore entertained in regard to the size of mains, have been erroneous, and that six inch pipes for long distances have very limited capacity. It may be convenient and useful to give the number of 12,000 cubic feet consumers that could be supplied by pipes of different sizes at an average distance equivalent to one mile, and remembering that if extended to two miles, the number would be reduced in proportion as 14 to 10, or about 30 per cent less. Boiler pressure 50 pounds, 1200 cubic feet in 16 hours=0.21 cubic feet in one second.

A 2	in. pipe	1 mile	carries	5.36	cub. ft., and	will supply	26 consumers
3	"	"		15.18	" "	72	"
4	"	"		30.36	" "	145	"
5	"	"		53.66	" "	256	"
6	"	"		83.4	" "	400	"
7	"	"		124.8	" "	595	"
8	"	"		171.6	" "	817	"
9	"	"		230.9	" "	1100	"
10	"	"		304.1	" "	1450	"
11	"	"		380.6	" "	1813	"
12	"	"		472.3	" "	2250	"

The number of consumers would be increased 40 per cent., and the velocity and capacity in the same proportion, if consumers were located uniformly along the line and not at the extreme end, as the above table supposes.

Another table will be required to estimate the quantity of coal consumed, which will be different for a given number of consumers upon each street, inasmuch as the boiler pressure is different, and the evaporation of steam depends upon the pressure. The following table gives in the first column the indicated pressure above the atmosphere, the second the corresponding temperature, the third the excess of temperature above 212°, the fourth the units of heat required to evaporate one pound from 212°, and the fifth column gives the pounds of water evaporated per pound of coal, assuming the Lockport regular duty

of 9 pounds water from one pound coal, under 25 pounds pressure as a basis.

1	2	3	4	5	1	2	3	4	5
0	212°	0	960	12.46	70	320°	108	1662	7.20
5	228°	16	1064	11.25	75	324°	112	1668	7.09
10	241°	29	1148	10.42	80	328°	116	1714	6.98
15	252°	40	1220	9.81	85	332°	120	1740	6.89
20	261°	49	1279	9.35	90	336°	124	1766	6.80
25	269°	57	1330	9.00	95	339°	127	1780	6.71
30	278°	64	1376	8.70	100	343°	131	1806	6.62
35	283°	71	1421	8.43	110	349°	137	1850	6.48
40	289°	77	1460	8.20	120	355°	143	1889	6.33
45	295°	83	1499	7.91	130	361°	149	1928	6.21
50	301°	89	1538	7.78	140	366°	154	1960	6.11
55	306°	94	1571	7.62	150	371°	159	1993	6.01
60	311°	99	1603	7.47	175	383°	171	2071	5.77
65	315°	103	1630	7.34	200	395°	183	2150	5.57

We have now developed data for an approximate estimate of cost of warming one square mile in a populous city containing within that area 20,000 consumers.

PLANT REQUIRED.

Ten batteries of 12 boilers of 80 horse power each.

The arrangement of the boiler houses will of course be controlled by the location, and where ground is very expensive it may be necessary to place them in second stories in a fire-proof building, and raise the coal with steam elevators, but for the purposes of this estimate it will be assumed that the boilers are on the ground floor in brick buildings covered with corrugated iron roof, and that each shed contains 2 batteries of boilers placed back to back, with the chimneys between. In front of the rows of boilers, spaces will be left of not less than 15 feet, and railroad tracks laid on each side next the walls, so as to deposit the coal inside opposite each boiler and avoid opening doors which will chill the building and increase loss by radiation.

Each boiler if placed side by side will occupy a space of about 7 x 22 feet, and a building to contain 24 boilers must be at least 114 x 80 feet, with about two chimney stacks, assumed to be sufficient without calculation. Five such buildings will be required, and each one would cost upon a single estimate, without reliable data, about $16,000.

Ground will be assumed at $50,000.

ESTIMATE OF 12 INCH MAINS.

It will be assumed that 10 mains will be laid on one of the sides of

the square to supply steam to the ten streets, also that the street mains will be 12 inches, for although the sizes of these street mains, if no circulation be provided, might be reduced from 12 to 6 inches from the commencement to the end of each street, yet as circulation is important in case of accident, it will be expedient to maintain the full sizes of the street mains, and also lay mains for connection and circulation on the opposite two sides of the square, thus making 22 miles of 12 inch street mains, or 116,160 feet.

The cost of a 12 inch main, laid as given by the Lockport estimate, is $5.70 cents per foot, net, including repaving.

It will be assumed that each block of 500 feet square will be supplied by running a pipe to the centre of the block to a distributing chamber and a line of pipes parallel to the mains at the back lines of the lots. The length of pipe for each block from the main to the distributing chamber will be 275 feet, and as there are 100 blocks, each block will require 2,400,000 cubic feet in 16 hours or 42 cubic feet per second.

If the street mains were not connected by a pipe at both ends so as to provide circulation, the pressures on the street mains would vary from 40 pounds to 5 pounds, and the size of the service pipe to pass 42 cubic feet per second would vary greatly, but with such connection a greater uniformity of pressure will be maintained, and it may be sufficient to assume 20 pounds as an average pressure, in which case a pipe of $3\frac{1}{2}$ inches diameter will be required for each of the 100 blocks, and the total amount of $3\frac{1}{2}$ inch pipe will be $275 \times 100 = 27{,}500$ lineal feet, the cost of which laid is, allowing for difficulties in laying, $1.50 per lineal foot.

From the middle of the block, a pipe will be carried each way an average of 125 feet, and the size of the pipe for this service will be $2\frac{1}{2}$ inches. The amount of $2\frac{1}{2}$ inch pipe will be $500 \times 100 = 50{,}000$ feet, and the price per foot $1.25.

It will be assumed that all the pipes named will be furnished by the company, and that the service pipes running into houses, and all the apparatus connected therewith, regulators, meters, traps, radiators, etc., will be paid for by consumers.

EXPENSES.

One pound of coal evaporates 9 pounds of water, and 1 pound of

water will make 27 cubic feet of steam containing 37 available units of heat to each cubic foot, or 1,000 units per pound of water, and 9,000 per pound of coal.

240,000,000 cubic feet of steam will therefore represent 493 tons per day, or say 500 tons, and for 200 days, 100,000 tons.

To handle 500 tons per day, in 16 hours will require two sets of hands, each set shoveling 250 tons in 8 hours, or 32 tons per hour, and as there will be 10 batteries of 12 boilers each, 4 men to each battery will be a minimum allowance. This will require 80 inside men to the two gangs.

For outside work, 40 men should be allowed, and to each battery two firemen, and a general superintendent over all.

For the general office there will be required a

President, salary	$5,000
Treasurer, "	3,000
Secretary, "	1,500
5 book-keepers, each	1,000
5 inspectors, "	900
5 repair men, "	600

With these data an approximate estimate of plant and operating expenses for one square mile will now be attempted.

PLANT.

120 eighty horse power boilers, set	$ 120,000
Boiler houses and stacks	80,000
Ground	50,000
116,160 feet 12 inch mains, $6	696,960
27,500 " 3½ " " 1.50	41,000
50,000 " 2½ " " 1.25	62,500
Cost of plant	$1050,460

OPERATION.

100,000 tons coal, $4	$400,000
120 hands for coal, $300	36,000
20 firemen, $900	18,000
General office employees	22,000
Stationery and incidentals	10,000
Taxes, insurance and legal expenses	20,000
Repairs	20,000
	$526,000

INCOME.

If 12,000 cubic feet per day be allowed to average consumers at a charge of $100 per annum, the gross income would be

20,000 consumers at $100	$2,000,000
Deduct expenses	526,000
Net revenue	$1,474,000

Per cent. on capital, 140.

If the charges should be reduced to $50 per year for 10,000 cubic feet per day of 16 hours, and 200 days, the gross income would be

	$1,220,000
Deduct expenses	526,000
Net income	$ 694,000

Per cent. for dividends or extensions, 66.

This estimate is very general, and the data purely hypothetical, but it will serve to give an idea of prospective profits from the introduction of the Holly system in populous cities. No account has been taken of condensation, for which an allowance of at least 3 per cent. should be made, representing an increase of $12,000 in coal consumption. And again the evaporation has been taken at 9 pounds of water per pound of coal, which is too large under the pressures supposed to be required, averaging 60 pounds, the evaporation due to which is $7\frac{1}{2}$ pounds, or an increase of 20 per cent. = $100,000. On the other hand it is not probable that the boiler station would be located at the corner of a square mile, and if near the centre, a large saving would be effected, as the mains would radiate in all directions from the station, and decrease in size towards the circumference, proper connections on both interior and exterior cross streets would serve to maintain greater equality of pressure, and a nearly uniform supply of steam in all parts of the district, without such a duplication of large mains as would be required if location was had at a remote point of the district to be supplied.

When the practical question is presented of supplying steam to a given city area, exact data will be furnished for the solution of the numerous and complicated questions connected therewith. One fact, however, seems to be clearly established by the consideration of the

questions presented, which is, that at any reasonable price for furnishing steam for heating purposes, save at a charge to consumers considerably below the cost of coal, the prospect of large dividends is greater than in almost any investment not of a speculative character, provided a consumption is assumed nearly to the limit of the capacity of the plant.

LOCATION OF STATION.

The expediency of locating the boiler station with reference to convenience of coal supply, or of steam distribution, will be considered by assuming a case and calculating results.

Suppose that instead of locating the boiler station at the corner of the square, as in the case estimated upon, the convenience of procuring coal should indicate a location one-half mile distant.

To carry the steam this additional half mile will require 10 12-inch mains, under an increased pressure of 20 pounds per square inch, making the lowest battery pressure 60, and the highest 100 pounds, and the average 80 pounds.

The evaporation under 80 pounds is 7 pounds water to one of coal, and under 60 pounds it is $7\frac{1}{2}$. The increase is 7.1 per cent., or on coal consumed $28,400

Condensation owing to high temperature, 2 per cent 10,000

Cost of five miles 12-inch main, $158,400.

Interest and repairs, 10 per cent $15,840

Extra cost of half mile in operation $44,240

Cost of Carting One-Half Mile.—100,000 tons coal 200 days = 500 tons per day, and one cart traveling ten miles would make ten half-mile trips; allowing for obstructions, 8 miles and 8 trips. $500 \div 8 = 65$ carts daily, or with reserve, say 80 carts and horses and 70 drivers. The cost of a horse, feed, harness, shoeing and stable expenses in New York is 60 cents per day; allow 75 cents to cover interest on plant and contingences. $1.75 will cover cart and driver. 8 tons hauled $\frac{1}{2}$ mile = 22 cents per ton. 100,000 tons carted cost $22,000; carried in pipes the extra cost of transporting the steam would be $44,240. It would therefore seem to be much cheaper to cart the coal and generate the steam as near as practicable to the district to be supplied.

Another important practical conclusion would seem to follow from

this discussion, which is, that economy both in plant and in expenses of operation would seem to indicate that a divided plant and short lines of supply, is preferable to fewer stations and longer mains; and this would evidently be most directly accomplished by locating the plant at or near the centre of the district, so as to radiate outwardly, and thus reach the limits on all sides with the shortest possible lines of main. But in planning works for any locality, local considerations will always have great influence, and will often modify greatly general conclusions.

POWER FURNISHED FROM STREET MAINS.

I see no reason to change the opinion expressed in my first preliminary report, that the Holly System is ordinarily adapted to the supply of small powers where the risk and annoyance of boilers is objectionable, and where power is required only occasionally. By simply turning a cock, power can be admitted to small cylinders for driving sewing machines in factories, printing presses, lathes, wood-working machinery and numerous other uses, where it will be cheaper to pay for steam than to erect a boiler and engine, purchase coal and employ an engineer to run it; often, too, the space saved is an object of prime importance to be utilized for other purposes.

But where large powers are required there can be no economy in taking the steam from mains, independently of the saving of space and risk of explosions, for the steam can be as economically generated by the large consumer as by the plant which supplies the mains, and the interest on cost of plant, loss by friction in transmission, and profits to company furnishing the steam, would be saved. In preparing estimates and plans for any given district, it may be expedient therefore to leave large consumers of power out of consideration, and confine the estimates to small powers, and to domestic, culinary and heating purposes, for which there is a very wide and profitable field of operation.. A horse power is a little less than half a cubic foot of steam per second, or 0.476.

CAPITAL, EXPENSES AND INCOME FOR THE MAXIMUM LENGTH OF STREET MAINS IN THE UPPER PORTION OF NEW YORK CITY, THAT CAN BE ADVANTAGEOUSLY SUPPLIED FROM ONE STATION.

The lower part of the city of New York is very irregularly laid out, and any plan for the introduction of steam mains must be controlled by local considerations. But in the upper portion of Manhattan Island, the avenues are parallel to each other and to the general course of the North and East Rivers, and the numbered streets intersecting them at right angles, are at uniform distances. The blocks into which the city is thus sub-divided, are rectangles, 700 feet long and 200 feet wide, containing 24 lots of 25 x 100 feet on the cross streets, and 8 lots on the avenues. The houses, however, do not generally occupy full lots, but frequently three houses will be built on two lots, four on three lots, or five on four lots.

It will probably be nearly correct to assume an average of 20 feet front, or 30 houses to a block, on the cross streets, and 10 on the avenues, or a total of 80 houses to a block. If 60 feet be allowed as an average for the streets, the number of blocks to a mile of avenue would be twenty, and the number of consumers per mile 1600.

The average space to be warmed in one of those New York houses cannot be estimated at less than 20,000 cubic feet, and when heated by furnaces, the consumption of coal, from the best data obtainable, is one ton for each 1000 cubic feet for the season.

One 12 inch or two 9 inch mains in each of the avenues would be required to supply this consumption of 32,000,000 cubic feet in sixteen hours, for one mile in length of avenue, and this will require 1100 horse power, or say a battery of 12 boilers rated at 100 horse power each.

Suppose a suitable location for a station could be found on Ninth Avenue, and that from this central point it should be proposed to send steam for one mile north and south, and from Sixth Avenue on the east to Twelfth Avenue on the west. That a nine inch main be laid on each side of each avenue, instead of one twelve inch main in the middle. The cost of two nine inch mains will be about $7.50 per lineal foot, and of one twelve inch main about $6.25 per foot, laid; but if the main is in the middle of the street, there must be service pipes and connections, at least equivalent in expense to two inch, or inch and a half pipes, parallel to the main, for the whole extent of the block, so

that if these service pipes can be dispensed with by laying two pipes near the curb, instead of one large main in the middle, the capital invested will not be greater with the two nine inch mains, than with one twelve inch.

The service pipe connections along the avenues may be made in one of two ways.

1st. Service boxes may be placed at shorter distances than usual, say at every 50 feet, and the service pipes connect with them directly, or

2d. It may be found preferable to have a supplementary pipe alongside of the main, containing brass stop cocks opposite every building, with which to make the connections, in which case, service boxes and expansion joints will be required, and at street intersections and from one street to the next the continuity of the mains will be unbroken, and it will be unnecessary, after the pipes are once laid, to tear up the pavements for any considerable extent to make connections when applications are received from new consumers.

ARRANGEMENTS FOR SUPPLY OF STEAM TO CROSS STREETS.

The mains being laid along the avenues, and the distance from curb to curb along cross streets being 700 feet, with 30 consumers of 20,000 cubic feet on each side, the arrangement obviously best for their accommodation will be a small pipe along the curb, furnished with expansion joints at intervals of 100 feet, and with brass cocks for the house connections.

It will probably be unnecessary to provide service boxes for these pipes as the water of condensation would be carried by the pressure of steam into the house circulation, to the advantage of the consumer, and would escape in the traps after parting with its heat.

The sizes of the pipes in the cross streets can be readily determined.

Assuming that each pipe is connected with mains on two avenues, the distance from each would be 350 feet, the number of consumers 15, and the consumption for heating purposes only, 5.25 cubic feet per second.

But if from any cause one main should be obstructed, it would be desirable that the pipe should have sufficient capacity to supply from the other main with which it connects, and therefore a capacity sufficient for 700 feet, 30 consumers and 10.50 cubic feet per second will

be given. The pipe required for this supply, with sufficient margin to maintain a proper pressure, will be 2 inches in diameter.

The pipes required to connect the station on Ninth avenue with the avenue mains should be 10 inches in diameter, and the number should be to Sixth avenue one main on each side of street, to connect with Ninth and Sixth avenue mains..... 2280 feet.

To Seventh avenue, 2 mains on each side..... 1520 "

To Eighth " 2 " " ..... 760 "

To Tenth " 2 " " ..... 760 "

To Eleventh " 2 " " ..... 1520 "

To Twelfth " 1 " " ..... 2280 "

Making a total of 27,360 feet, and with a connecting main at the end of the mile crossing all the avenue mains, 4560 feet, the total length of 10-inch mains will be 31,920 feet.

The 9-inch mains required for this area of two miles long and from Sixth to Twelfth avenues wide, will be

On Sixth avenue	2	miles
On Seventh "	4	"
On Eighth "	4	"
On Ninth "	4	"
On Tenth "	4	"
On Eleventh "	4	"
On Twelfth "	2	"
126,720 feet	24	"

The number of blocks to a mile along avenues being 20, the two miles will be forty, and from Sixth to Twelfth avenues there will be 240 blocks.

Each block requires two lines of 2-inch pipe, say 725 feet long, or 1450 feet, and the 240 blocks will therefore require 348,000 feet.

240 blocks of 80 consumers of 20,000 cubic feet each, will contain 19,200 consumers, and require 7000 cubic feet of steam per second= 14,000 horse power, nearly. The area being $1\frac{3}{4}$ square miles=8000 horse power per square mile.

20,000 consumers of 20,000 cubic feet of steam per 16 hours=400,000,000 cubic feet=25,000,000 per hour, which is nearly 1,000,000 cubic feet of steam per hour for each of the 24 miles of 9 inch main.

The coal required will be 98,000 pounds=49 tons per hour—800 tons per day, and 160,000 tons per year of 200 days, not including power.

If the boilers are of size sufficient to evaporate each 100 cubic feet of water per hour, the number required will be 140. These boilers may be placed in a fire proof building in four stories, 36 in each story.

As there are 24 mains, a battery of 6 boilers will be required for each main.

If these boilers be placed in two rows of 18 each, on each floor the space required will be about 60 x 150.

The coal supply presents some difficulties. There should be storage at the boiler house for at least one week, which will require a space equivalent to 100 feet square and 15 feet high. There should be a track connecting with the wharves, the coal hauled in short 5 ton cars, raised by elevators and dumped on the storage ground. The space required for building, elevators and storage should be at least 200 feet square, and it would be desirable to have an equal amount in addition for storage at the wharf.

The plan of the boiler house and the form of boiler will require the most careful consideration. It is possible, however, that a building with four stories, the boilers in each story arranged with backs against the wall, in batteries of 6, an elevated track to the line of which cars can be raised by elevators at each end, and by means of which coal can be dumped in a wide space provided for that purpose in front of the boilers, will be found most convenient.

A revised estimate on the basis of the data now presented will be given :

PLANT.

Lot, 200 feet square	$ 50,000
Building, 4 story, fire proof	75,000
144 boilers, including setting, $1,000	144,000
32,000 feet 10-inch mains, laid, $4.50	144,000
127,000 " 9 " " " 4.00	508,000
348,000 " 2 " " " 1.00	348,000
60,000 " 1½ " " " on avenues, 80 cents	48,000
48 feed pumps, $250	12,000
20,000 brass cocks for supply connections, 40 cts	8,000
200 street valves, $60	12,000
Incidentals	50,000
	$1,399,000

EXPENSES.

160,000 tons coal, $3	$480,000
100 laborers, $300	30,000
50 firemen, $400	20,000
10 mechanics, $900	9,000
President	10,000
Engineer chief	6,000
2 assistants	4,000
Treasurer	5,000
Book keepers	6,000
25 inspectors	25,000
Taxes, etc.—legal expenses	100,000
	$695,000

INCOME.

20,000 consumers of 20,000 cubic feet each $100	$2,000,000
Less expenses	700,000
	$1,300,000

Capital $1,400,000.

Net earning, with full consumption, 93 per cent.

Net earning with half consumption:

Income	$1,000,000
Expenses	440,000
Surplus	$560,000

Per cent. on capital 56.

NOTE.—I see no reason why net earnings should not make a relative showing nearly as good in smaller places, on small lines of pipe, whenever occupied up to near their full capacity. The amount of investment and running expenses will be reduced in proportion to extent of space to be warmed, for a given district.

SUGGESTIONS IN REGARD TO A PLAN OF OPERATIONS.

1st. Parties desiring to introduce the Holly System, and who have secured the necessary license and completed their organization, will require a plan of the district to be supplied.

2d. A location for the boiler station as nearly central as possible to the area to be supplied.

3d. The locality should be thoroughly canvassed by committees, and the number of consumers, the exact location on the plan, the volume of space to be heated, or the amount of power to be furnished, ascertained with the greatest accuracy possible; also the probable prospective increase in the demands, and at what points it will be required. On these data will depend the sizes of mains, the capacity of the central station, and the amount of capital required.

4th. This information having been obtained by the local organization, a competent engineer will then be required to prepare plans, specifications and estimates, and calculate and arrange all the details of the work.

5th. The work can be done under a competent superintendent, if such an one can be found, by day labor, or a contract can be made with responsible parties, as gas and water works are usually contracted, the contractor taking a liberal portion of stock as part of the consideration, where such arrangement is desired.

GAS VERSUS STEAM FOR HEATING PURPOSES.

Circulars have been extensively distributed in Philadelphia and elsewhere, conspicuously headed "*The Fuel of the Future*," and claiming for a gas produced from the decomposition of water, superior economy and efficiency as a combustible over any other known fuel or mode of heating.

To remove erroneous impressions it becomes necessary to devote a brief space in this report to an examination of these claims.

How the Gas is Produced.—The gas is generated by passing the vapor of water through a furnace filled with coal in a state of ignition, by which means decomposition of the steam is effected, and the resulting gases are hydrogen and carbonic oxide.

When required for illuminating purposes, these gases are enriched with carbon furnished by naptha or petroleum.

The cost of illuminating gas, for the items of petroleum, coal, labor and purification, amount to $37\frac{1}{2}$ cents per 1000 cubic feet.

The testimonials and reports of experts would seem to indicate that a very superior illuminating gas is produced by this process, and at this price.

For heating and metallurgical purposes a much cheaper gas can be

produced, as the petroleum and naptha can be dispensed with, and such gas, it is claimed, can be produced at 8 cents per 1000 cubic feet.

The question for examination is, can such gas, produced at the works at a cost of 8 cents at the present low price of coal, compete successfully with steam as a source of heat for domestic and manufacturing purposes, after adding a sufficient sum to cover repairs and deterioration of plant, and to pay dividends?

Composition of Water Gas.—One pound contains:

Oxygen	0.0174
Carbonic Acid	0.0637
Nitrogen	0.0880
Carbonic Oxide	0.7097
Hydrogen	0.0747
Marsh gas	0.0465

It requires for perfect combustion 5.9 pounds of air.

The number of heat units developed in combustion = 7.727.

The specific gravity of the gas is 0.54.

Fifty pounds of coal it is claimed will produce 41.16 pounds of gas = 1000 cubic feet at a cost of eight cents.

COMPARATIVE STATEMENT.

One pound of coal will produce $\frac{41.16}{50} = .823$ pounds of gas.

The heat units developed in combustion $= .823 \times 7.727 = 6359$.

One pound of coal will evaporate 9 pounds of water, and 9 pounds steam contain of available heat units = 9900.

The steam is produced under a pressure of 50 or 60 pounds to the square inch, and requires no other pressure to carry it to a consumer a mile or more distant.

The gas on the contrary is produced under a pressure of only six inches of water, or less than one-fourth of a pound, and the discharge under this head as compared with steam through a pipe of any given length or diameter, would he as one to sixteen.

A cubic foot of steam under the pressure at which it is produced, say 60 pounds, contains 210 units.

A cubic foot of gas under the pressure at which it is produced contains 318 units.

Taking both gas and steam at atmospheric tension one cubic foot of steam will contain 42 units, one cubic foot of gas will contain 318 units; or in proportion as one to $7\frac{1}{2}$, but as the discharges of quantity are as sixteen to one in favor of steam, the gas mains must be of much larger dimensions or power must be applied to cause the gas to circulate at long distances from the generator.

The patentees of the gas process do not claim that they have perfected any economical plan for using it as fuel for domestic purposes. If consumed in furnaces in the cellar, in open fire-places or in stoves, there must be nearly the same waste of heat units by escape through the flues as in burning coal in the ordinary way, while the units of heat in a pound of coal are 82 per cent. greater than in a pound of gas, at a cost to the consumer of less than half, without allowing profits on gas manufactured.

I have omitted profits on both sides in this comparison, allowing one to offset the other, and conceding that 1000 cubic feet, or 41 pounds of gas can be manufactured at the works for eight cents. The present cost of coal by wholesale being $2.25 per ton, the cost of a ton of gas would be $4.00 per 2000 pounds, developing 15,454,000 heat units, a large percentage of which would be lost in subsequent combustion, while the coal would contain 26,000,000 heat units, of which 20,000,000 could be fully utilized in steam.

It seems fair therefore to consider that the cost of heat units furnished to the consumer in steam would be less than half the cost of an equal number of units in the form or gas.

STEAM STOVE.

A most important extension of the field of useful application of the Holly System is found in the steam stove, the success of which has been demonstrated by numerous tests in the presence of connoisseurs and caterers of prominence.

It is now conclusively established that steam under a pressure of 40 pounds per square inch, and a consequent temperature of 300°, can be utilized as a substitute for stoves, ranges and ovens for at least nine-tenths of the cooking required for families and hotels, and that the cooking done by steam is a wonderful improvement upon the ordinary mode. Succulent vegetables require no water; they contain sufficient of themselves to cook thoroughly without any addition, and the differ-

ence in flavor, of boiling in their own juices and boiling in the ordinary way in water, would scarcely be credited. The food boiled in water being comparatively tasteless and insipid.

By this process steaks, chops, ham and eggs, can be fried or broiled, beans, meats, apples, potatoes, and bread baked, rice and all other vegetables boiled, and one great peculiarity of the process is that scorching is impossible, and while the time required to prepare food is surprisingly short, the food cannot be spoiled by over-cooking.

Another peculiarity of the process is that onions, cabbage, and other articles which emit ordinarily offensive odors in cooking, can be prepared for the table without the most sensitive olfactories being cognizant of the fact.

On Saturday, Feb. 22, 1879, at 61 Beekman street, the following culinary operations were performed in the presence of a large number of invited guests, all of whom expressed surprise and gratification at the perfect success of the experiments, and especially at the peculiar sweetness, juiciness, and natural flavor of all the articles experimented upon.

1. Mutton, leg, 8 pounds, baked; time one hour 10 minutes; thoroughly done, but not overdone. Mr. Coleman, of Burnett House, Cincinnati, expressed the opinion that it could have been removed from the oven 20 minutes sooner.

2. One pound rice boiled 40 minutes, then removed; found to be perfectly soft. It was then replaced and without being stirred was allowed to remain one hour and a half longer, to prove that it could not be scorched.

3. Three large apples, baked; removed in 30 minutes, done perfectly; could have been removed sooner.

4. Eight onions, about size of large walnuts, placed in tin vessel about size of pint cup, with cover, and this placed inside of one of the covered compartments of stove; removed in 37 minutes, soft and well boiled.

5. Coffee, 5 half pints, time very short, but not noted; about ten minutes.

6. Potatoes, baked; two large Irish and two large sweet; in oven 40 minutes; well baked.

7. Potatoes boiled, two large Irish and two large sweet; water cold, time 28 minutes. The water was allowed to evaporate, which could be done safely, as scorching is impossible. Potatoes opened very dry and mealy.

8. Plum pudding, mixed and batter placed in receptacle, remained in 37 minutes; nicely browned on outside, light and spongy inside, and very palatable.

9. One beefsteak and two mutton chops in broiler, removed in 7 minutes, thoroughly cooked. No part raw and remarkably juicy.

10. Large slice of ham in broiler, turned in 4 minutes, finished in 7 minutes from commencement. It was noticed by gentlemen present that when cold, instead of being hard, the ham remained soft and juicy.

11. Eggs fried in 3 minutes, done just right.

12. Cabbage, boiled, 40 minutes.

13. Beans and pork, nicely browned and soft, one hour.

After these experiments were completed, a thermometer was placed in the oven, which indicated a temperature of 282°.

The stove was then cleaned and time noted. To cleanse it thoroughly required 14 minutes.

Form of Stove.—The stove experimented upon was 34 inches long, 18 inches wide and 10 inches deep. It stood about 30 inches high, and, except the top plate, was jacketed with felt to prevent radiation. The lower part, between the bottom of the stove and the floor, was cased with walnut, and presented a neat appearance. This space was not utilized, but could be to great advantage in warming plates and keeping dishes warm without drying.

In the top plate were compartments, all of which were 8 inches deep in the inside, leaving a space below sufficient for steam circulation. The largest of these compartments was 15 inches by 9; two others were 8 by 4 inches, one was 8 by 5 inches, and two circular ones $8\frac{3}{4}$ inches in diameter.

The broiler was a separate stand, 12 inches diameter and 2 inches deep, the sides and bottom well scoured and bright. The compartments in the stove were clean, but not scoured.

One pail of water, containing by weight 20 pounds, was poured into the oven; it boiled from a temperature of 40° in two minutes.

Suggestions.—The stove, instead of being rectangular, should be circular in form, and banded with wrought iron, and before putting any one upon the market for sale, it should be tested to 150 pounds, so as to render accidents, by bursting, impossible.

There should be no corners in the compartments, but their form should be such as to facilitate the operation of cleaning as much as possible. The manufacturer could readily rig up an apparatus run by power, to scour the interior surface, using polishing felt and sand, or some other of the numerous devices that could be suggested for that purpose. The labor of cleaning after cooking would not then occupy five minutes. No kettles, pots or pans to be washed.

Cost of Fuel.—Mr. Ashcroft proposes to ascertain by direct experiment, by condensing and weighing the water, the actual amount of steam required and the consumption of coal represented, but in the absence of such experimenting, I have made pretty careful calculations based upon the laws of radiation, and find that the actual cost of preparing food for the table, and for all kitchen requirements, will be surprisingly small. The kitchen in summer by reason of overheating, is usually a place of great discomfort to the housewife. This will be avoided with steam, as it can be turned off the moment it is not required for use.

The poorer classes living in single rooms, could have small stoves with only two or three compartments, which would suffice for their limited culinary requirements, and which would also serve as radiators to furnish heat. No fuel would be used, no risks incurred from fires, and no children's lives destroyed by burning in the temporary absence of the mothers. The catalogue of casualties from such causes would be reduced.

When tenement houses, those hot-beds of vice, crime, and pestilence, shall be abandoned, and their unfortunate occupants removed to healthy suburban localities, shall be permitted to breathe pure air and behold heaven's sunshine, where they can be brought to their work and returned to their homes by compressed air motors at a speed limited only by considerations of safety, and at a cost for propelling power less than one-third the cost of coal in street dummies; when three meals can be cooked and apartments warmed at a nominal cost by the Holly System, then will a stride be taken in the amelioration of the

condition of the working classes, and in their moral, sanitary and intellectual advancement, in comparison with which the millions expended by benevolent and charitable associations under the appeal of eloquence, will sink into insignificance.

Make men comfortable at home, and the temptation to crime is removed; enable them with the pittance earned by labor to provide more largely the necessaries of life, and the ground work is laid for moral and Christianizing influences, for the good seed cannot take root where the ear is closed to all but the cries of want, and the conscience seared, and the wolves of famine, cold and pestilence are howling at the door.

Is it extravagant, visionary, enthusiastic, to class the Holly Steam System, the Ashcroft stove, and the pneumatic motor, as agencies of the highest order in advancing the interests and in promoting the comfort and happiness of suffering humanity? If so, I am an enthusiast. I may not live to see the bright dreams of the future realized, but if capitalists will refrain from excessive charges, humanity will reap large benefits from these inventions.

ERRATA.

Page 14, paragraph 1, lines 3 to 14, see supplement.
Page 38, first line of table for .9375 insert .0375.
Page 39, line 19, for $\sqrt{S}$ read $\sqrt{5}$.
Page 61, line 11, for 1200 read 12000.
Page 62, substitute table of evaporation in supplement.
Page 63, line 10, for *net* read *not.*
Page 67, line 12, for *ordinarily* read *admirably.*
Page 69, line 12, for *and* read *only.*
Page 72, Note line 3, for *occupied up* read *operated.*
Page 78, last paragraph, line 4, for *where* read *when,* and in line 7, for *three* read *their.*
Page 79, line 3, for *appeal* read *appeals.*

EXPLANATION.

The report was printed at Lockport, and with the exception of portions containing algebraic formulæ, the author had no opportunity of correcting proofs. The errors, however, are less numerous and important than it was reasonable, under the circumstances, to expect. He did not see the Title Page until the report had been printed and bound, and the matter for certain alterations in the table of evaporation was received too late for insertion, and will be found in the supplement.

H. H.

SUPPLEMENT.

A remarkable diversity of opinion is found to exist amongst practical engineers and boiler manufacturers in regard to the effects of increased pressure upon evaporation; some contending that the quantity of water evaporated under high boiler pressures is greatly reduced—others that the difference is inconsiderable, and others again, admit that the question is new to them and has not received attention.

On page 14 an attempt was made to explain certain statements made by a mechanical engineer of large experience, and accepted at the time as facts, but further consideration has satisfied the writer that the facts are overstated, and that the theory upon which they were attempted to be explained requires modification. A revised table was forwarded to Lockport for substitution, but the form having been printed the correction was too late for insertion.

The fact of a difference of evaporation under pressure is very generally admitted by mechanical engineers, and is moreover confirmed by direct experiments in England where as the result of 28 carefully conducted experiments it was found that the coal required to evaporate 20 cubic feet of water at pressures from 0 to 60 lbs. above atmosphere varied from 195 to 210 lbs., or a difference of 8 per cent. with 3 atmospheres.

No explanation of this fact, so far as the writer knows, has been attempted, but it would seem reasonable to assume that the consumption of coal should be in proportion to the work done.

If we suppose one cubic foot of water to be confined in a cylinder of one square foot sectional area and of indefinite height, and heat applied to convert the water into steam under the atmospheric pressure of 14.7 pounds, the space through which this weight would move would be 1700 feet, and $1700 \times 14.7 \times 144 = 3,598.560$ foot pounds of work in the conversion of one cubic foot of water into steam under one atmosphere of pressure.

Assume as a second illustration that the pressure is 200 lbs., the temperature will be 387 degrees and the space occupied by the steam under this pressure 158 cubic feet. The foot pounds of work in the conversion of the water into steam under this pressure will be 4.550,000, an increase of 951.440 foot pounds or 26 per cent.

The following table of evaporation is based on the Lockport duty of 9 lbs. water to 1 pound coal under 25 lbs. pressure, and assumes that the consumption under any other pressure is in proportion to foot pounds of work.

Column 1 represents total pressure of steam.
" 2 " temperature.
" 3 " cubic feet steam from 1 cubic foot water.
" 4 " foot pounds of work in expanding.
" 5 " pounds of water evaporated by 1 lb. coal.

1	2	3	4	5	1	2	3	4	5
14.7	212	1700	3598560	9.783	80	316	362	4133000	8.516
20	228	1281	3689000	9.542	85	320	342	4151000	8.481
25	241	1044	3759000	9.364	90	324	325	4169000	8.444
30	252	883	3815000	9.227	95	328	310	4178000	8.426
35	261	767	3866000	9.116	100	332	292	4205000	8.370
40	269	679	3911040	9 000	110	339	271	4293000	8.201
45	276	610	3963000	8.850	120	341	251	4338000	8.126
50	283	554	3989000	8.825	130	352	233	4362000	8.070
55	289	508	4024000	8.748	140	357	218	4395000	8.015
60	295	470	4061000	8.668	150	363	205	4428000	7.950
65	301	437	4079000	8.628	175	376	178	4486000	7.847
70	306	408	4097000	8.592	200	387	158	4550000	7.742
75	311	383	4115000	8.553					

STEAM REQUIRED PER HORSE POWER.

It is customary for parties using power to furnish other parties with steam, for a consideration, and the charge made in Philadelphia varies from $75 to $125 per horse power per annum.

This is a very uncertain basis of charge for the steam consumed per horse power is a very variable quantity, being dependent on the degree of expansion in the cylinder.

If steam is used at a low pressure and without expansion, it requires fully one cubic foot of water evaporated per hour per horse power, or .472 cubic feet per second, as can be readily shown Suppose effective pressure = 20 pounds. The foot pounds of effective work in evaporating one cubic foot would raise $144 \times 20 = 2880$ pounds to a height

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of 767 feet in one hour, or 36.800 foot pounds per minute, which is slightly in excess of a horse power. At lower pressures a cubic foot of water evaporated would produce less and at higher pressures more, assuming that the steam is used without expansion in the engine cylinders. Now, suppose steam to be used expansively. If the pressure in the mains be 60 pounds, the expansion in the cylinder cannot be quite as much as 3, and the per centage of gain 110, so that in this case half a cubic foot of water per hour would furnish a horse power, or $3\frac{1}{2}$ pounds of coal. At this rate the margin of profit in supplying power would be very large to a company with numerous patrons, and at the same time it might prove quite economical to the consumer. If higher pressures and greater expansion could be used, the economy would be still greater.

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